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Vegetation of *Little Bora* Nature Conservation Trust Agreement, North Western Slopes, New South Wales

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Abstract: The vegetation of the *Little Bora* Nature Conservation Trust Agreement property (560 ha in area), 8 km south east of Bingara (lat 29° 55'S long 150° 37') in the Gwydir Shire and within the Nandewar Bioregion is described. Eight vegetation communities are defined based on flexible UPGMA analysis of cover-abundance scores of all vascular plant taxa. These communities are mapped based on ground truthing, ADS40 imagery interpretation, topography and substrate. Communities described are: 1) *Melaleuca bracteata – Eucalyptus melanophloia – Eucalyptus camaldulensis* Woodland, 2) *Callitris glaucophylla – Eucalyptus melanophloia – Eucalyptus albens* Woodland, 3) *Callitris glaucophylla – Eucalyptus melanophloia – Brachychiton populneus* Woodland, 4) *Eucalyptus albens* Woodland, 5) *Eucalyptus caleyi – Eucalyptus albens – Callitris glaucophylla* Woodland, 6) *Callitris glaucophylla – Eucalyptus melanophloia – Eucalyptus albens* Woodland, 7) *Austrostipa verticillata – Austrostipa scabra* Derived Grassland, 8) *Eucalyptus melliodora – Eucalyptus dealbata* Woodland. A total of 232 vascular plant taxa were found of which 14% were considered exotic in origin. 66 ha of listed threatened communities were mapped along with populations of a currently listed Extinct plant (*TSC* Act) *Dodonaea stenophylla*.

Key words: vegetation, mapping, condition, conservation, Little Bora, floristics, woodland, north western slopes, Bingara

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Introduction

Little Bora Nature Conservation Trust property is located within the Nandewar Bioregion on the North Western Slopes of New South Wales. The property lies approximately 8 km south east of Bingara (lat 29° 55'S long 150° 37') in Gwydir Shire local government area . The property contains 560 ha of private lands and was purchased by the current owner from the Nature Conservation Trust in August 2007, the first property to be sold on to a private landholder by this revolving fund. Its history has been dominated by logging with a local mill being once established on the property and in later years by grazing of cattle (G. Chorley, *pers. comm.* 2012).

The Bingara Community Conservation Reserves which include Derra Derra, Mehi, Molroy, Munro, Murchison, Noonga, Salmon and Sepoy occur within the vicinity of *Little Bora* (Fig. 1). These reserves were primarily State Forests and Crown Lands although some sections (Noonga) were privately owned. Another Nature Conservation Trust Agreement property, *Euroka* occurs nearby (Fig. 1). These reserves, including *Euroka*, have recently had their flora and vegetation surveyed and vegetation mapping produced and share many similar landscapes and vegetation types (Benson *et al.* 1996; Hunter 2009abl; Hunter 2010ab; Hunter 2011b; Hunter 2012abcd; Hunter 2013b).

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The study area is a rugged landscape primarily of metasedimentary geology. Altitudes range from 310–660 m above sea level. The topology of the landscape is of extensive elevated ridgelines than run in a south eastern direction. The northern boundary forms part of lowland areas associated with the Gwydir River. The property also contains two creek lines that flow into the Gwydir River, the larger being Little Bora Creek.

This paper provides part of the results of a flora survey conducted to provide baseline data for the future management of the private conservation area, to construct a map of vegetation communities and their condition and to provide information on the distribution of rare taxa. A comparison of different forms of community circumscription and mapping is also made, particularly between methods based on floristic analysis and that required by Threatened Ecological Communities (TECs) listed under the Commonwealth *Environmental Protection and Biodiversity Act* (*EPBC*) and the New South Wales *Threatened Species Conservation Act* (*TSC*). This information will be used to assist the development of appropriate management strategies (Hunter 2012d).

Methods

Forty eight, 20 x 20 m quadrats were surveyed for vascular plants scored using the Braun-Blanquet six point cover abundance scale (Westhoff & Maarel 1978) in the *Little Bora* Nature Conservation Trust Agreement property. Quadrats were placed using a stratified random method using: altitude, aspect and physiography (crest & upper slope, lower slope & flats, open depressions). At each full floristic survey site structural information was also recorded which included the length and density of logs on ground, tree diameter sizes, tree height and the number of hollows. This information was used along with other notes taken to assist in the mapping of condition classes. A further 17 sites which only recorded the dominant three species in each of the major structural layers were also placed across the property to assist in recognition of vegetation types when conducting ADS40 image interpretation. The survey was conducted over a period of two days during late September of 2012.

Analyses and data exploration were performed using options available in the PATN 3.2 Analysis Package (Belbin 1995a, b). For final presentation of results all species and their relative abundance scores were used and the analysis performed using

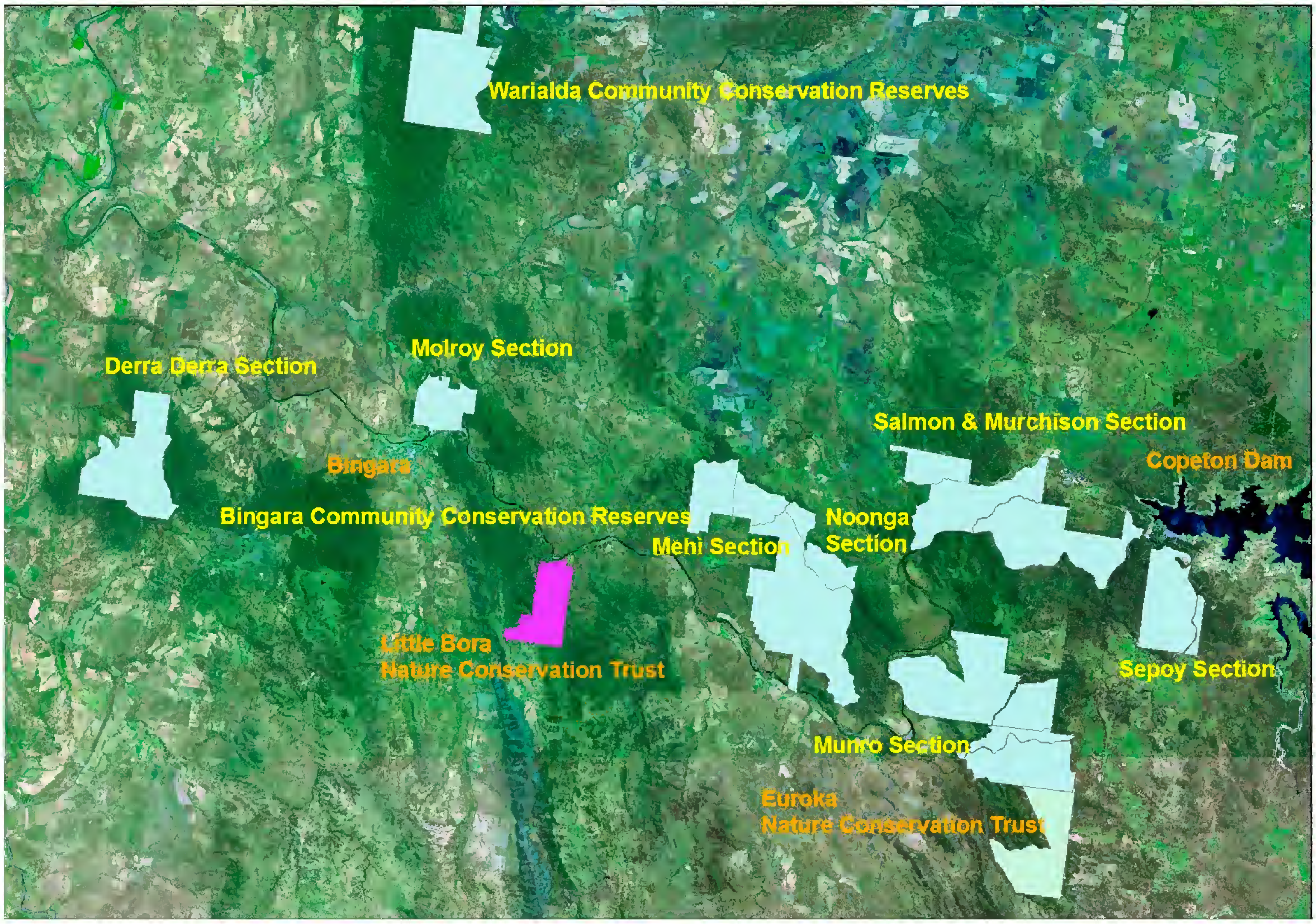
Warialda Community Conservation Reserves
Molroy Section
Derra Derra Section
Salmon & Murchison Section
Copeton Dam
Bingara
Bingara Community Conservation Reserves
Noonga Section
Mehi Section
Little Bora
Nature Conservation Trust
Sepoy Section
Munro Section
Euroka
Nature Conservation Trust

Fig. 1. Location of *Little Bora* Nature Conservation Agreement and other reserves in the Bingara area.

Kulczynski association measure which is recommended for ecological applications (Belbin 1995ab) along with flexible Unweighted Pair Group arithMetic Averaging (UPGMA) and the default PATN settings. Each site (full floristic and RDP) were assigned a community mapping code retrospectively based on the results of the statistical analysis of the full floristic survey sites. The sites and their assigned community identity were re-projected onto satellite (ADS40) imagery using GIS software. These sites, the notes taken on traverses, structural characteristics seen on satellite images along with projected topographical and rock type information was used to delineate vegetation polygons. This methodology follows the guidelines for vegetation mapping provided within the Native Vegetation Interim Type Standard (Sivertsen 2009).

Threatened Ecological Communities listed under the NSW *Threatened Species Conservation* Act or Commonwealth *Environmental Protection & Biodiversity Conservation* Act are not always direct correlations to floristic units and as such each mapping unit was scored in a subsidiary field for its potential inclusion within any listed TEC. Quality was scored in three categories which were derived based on a summation of information collected at each site including recognisable disturbances, weed infestations and features known to be of importance to community quality and fauna habitat. Sites in moderate condition often lacked some important fauna habitat elements. Commonly these were stands of younger-aged trees representative of the original overstorey, with some isolated mature trees and a predominantly native understorey. Low condition sites often had little of the original overstorey cover, supported few if any features important for fauna habitat, and had high weed infestations. While these subtypes of condition are generally due to time constraints and not fully quantifiable, they form an important assessment to assist in management planning. With more time and resources this type of assessment can be improved whereby appropriate attributes are specifically measured and analyses performed to more critically and objectively separate condition classes.

Results and Discussion

In the *Little Bora* Nature Conservation Trust Agreement property, eight vegetation communities were recognized at the dissimilarity measure of 0.74; a summary of community relationships is given in the dendrogram (Figure 2). Delineation of community boundaries and their condition are presented in Figures 3 and 4. Over the two day survey period a total of 232 vascular plant taxa were found from 70 families and 158 genera with 14% being exotic in origin. Approximately 65% of the property was considered to be in good condition with only 7% being in poor condition (Table 1). As is typical communities in good condition were restricted to the hills and ridges and more inaccessible country while the more fertile country on the lower slopes and valleys were more likely to be in moderate to poor condition.

Table 1: Selected attributes of the eight defined communities in the *Little Bora* Nature Conservation Trust Agreement property.

Community	Number of Sites	Richness per 400 m^2 (average)	Number of Species	Number of Introduced Species	Good	Moderate	Poor
C1: *Melaleuca bracteata – Eucalyptus melanophloia – Eucalyptus camaldulensis*	6	29–39 (34)	85	14	13.1 ha (2%)		
C2: *Callitris glaucophylla – Eucalyptus melanophloia – Eucalyptus albens*	29	27–40 (31)	147	12	296 ha (53%)	87.8 ha (16%)	33.6 ha (6%)
C3: *Callitris glaucophylla – Eucalyptus melanophloia – Brachychiton populneus*	6	24–34 (30)	76	3	20.3 ha (4%)	20.5 ha (4%)	5.2 ha (1%)
C4: *Eucalyptus albens*	1	30	30	3		0.1 ha (<0.0%)	
C5: Eucalyptus caleyi – Eucalyptus albens – Callitris glaucophylla	5	20–27 (23)	59	4	33 ha (6%)		
C6: *Callitris glaucophylla – Eucalyptus melanophloia – Eucalyptus albens*	13	18–55 (30)	116	21		1 ha (<1%)	38 ha (7%)
C7: Austrostipa verticillata – Austrostipa scabra	3	18–32 (18)	46	11			4.7 ha (1%)
C8: Eucalyptus melliodora – Eucalyptus dealbata	2	15–22 (19)	29	11			5.2 ha (1%)
					362.4 ha (65%)	108.4 ha (19%)	38.8 ha (7%)

Table 2: Condition and area (hectares) of Threatened Ecological Communities in the *Little Bora* Nature Conservation Trust Agreement property

TEC Type	Good	Moderate	Poor
Aquatic Ecological Community in the Natural Drainage System of the Lowland Catchment of the Darling River (FIsheries Act)	13		
White Box – Yellow Box – Blakely's Red Gum Grassy Woodland and Derived Native Grassland (*EPBC* & *TSC* Act)		0.5	5
Semi-evergreen Vine Thickets of the Brigalow Belt (North & South) and Nandewar Bioregions (*EPBC* & *TSC* Act)	21	21	7

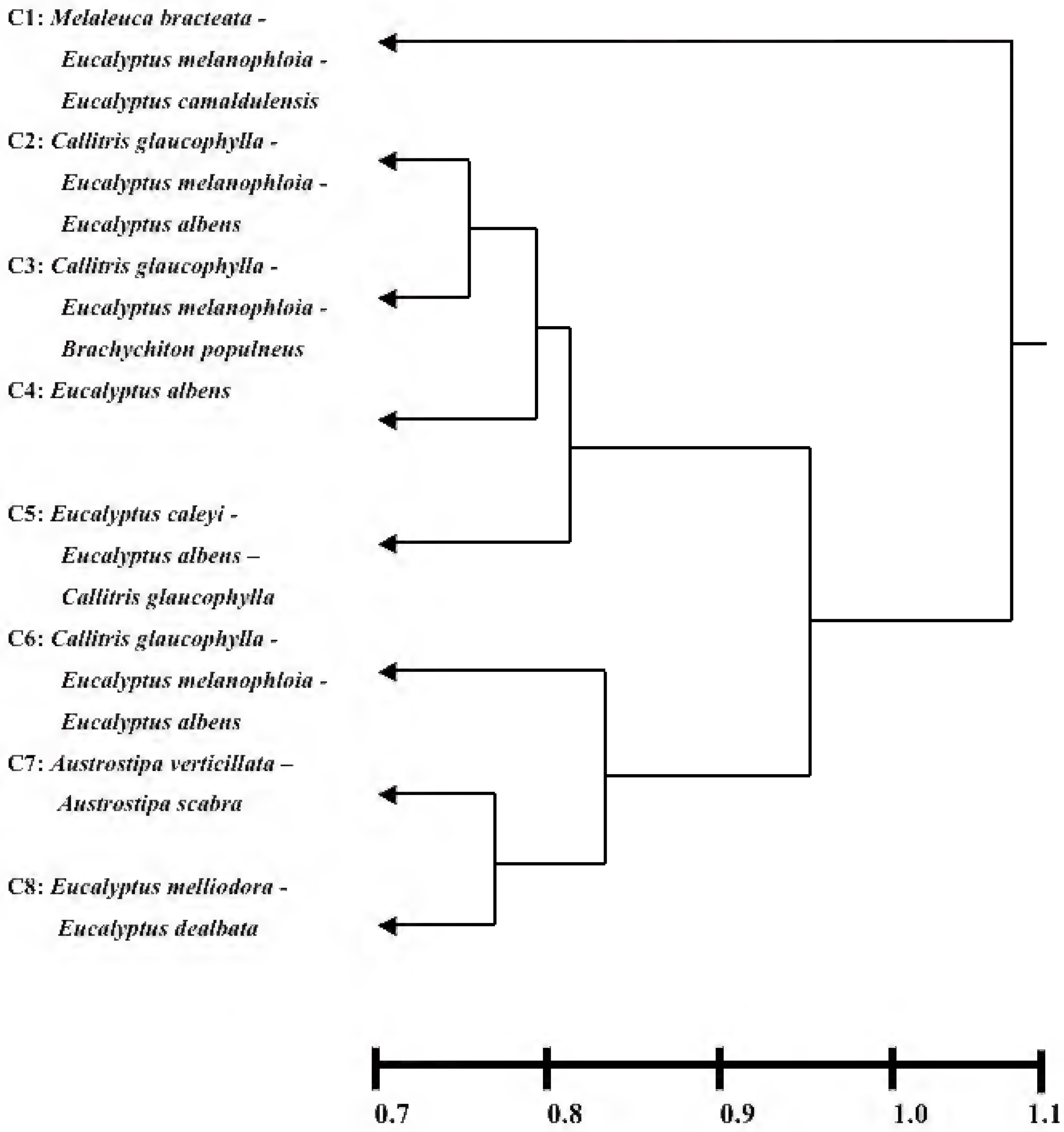
C1: Melaleuca bracteata - Eucalyptus melanophloia - Eucalyptus camaldulensis
C2: Callitris glaucophylla - Eucalyptus melanophloia - Eucalyptus albens
C3: Callitris glaucophylla - Eucalyptus melanophloia - Brachychiton populneus
C4: Eucalyptus albens
C5: Eucalyptus caleyi - Eucalyptus albens – Callitris glaucophylla
C6: Callitris glaucophylla - Eucalyptus melanophloia - Eucalyptus albens
C7: Austrostipa verticillata – Austrostipa scabra
C8: Eucalyptus melliodora - Eucalyptus dealbata
0.7
0.8
0.9
1.0
1.1

Fig. 2. Summary dendrogram of the full floristic dataset of sites using Kulczynski association and flexible UPGMA fusion strategy recorded in the *Little Bora* Nature Conservation Trust Agreement property. Delineation of communities occurs at a dissociation of 0.75.

Vegetation communities

Community 1: *Melaleuca bracteata* (Black Tea-tree) – *Eucalyptus melanophloia* (Silver-leaved Ironbark) – *Eucalyptus camaldulensis* (River Red Gum) Riparian Layered Woodland

Structure: highly variable but predominantly a layered shrubby woodland, woodland, closed scrub or closed shrubland or dry rainforest.

Trees: *Eucalyptus melanophloia, Eucalyptus camaldulensis, Callitris glaucophylla, Angophora floribunda, Eucalyptus dealbata, Eucalyptus melliodora.*

Tall shrubs: *Melaleuca bracteata, Alectryon subdentatus, Geijera parviflora, Alstonia constricta, Acacia leiocalyx*

Shrubs: *Notelaea microcarpa, Phyllanthus subcrenulatus, Nyssanthes diffusa, Cryptandra amara* var. *floribunda, Bursaria spinosa, Abutilon oxycarpum, Solanum parvifolium, Xanthorrhoea johnsonii, Pimelea neo-anglica, Olearia elliptica, Macrozamia diplomera, Isotropis foliosa, Hibbertia obtusifolia, Dodonaea viscosa, Carissa ovata.*

Climbers & trailers: *Eustrephus latifolius, Pandorea pandorana, Glycine tabacina, Glycine microphylla, Desmodium varians.*

Ground cover: *Microlaena stipoides, Adiantum atroviride, Scleranthus biflorus, Daucus glochidiatus, Poa sieberiana, Geranium solanderi, Wahlenbergia communis, Urtica incisa, Galium migrans, Dichondra repens, Carex incomitata, Austrostipa verticillata, Swainsona galegifolia, Rumex brownii, Ranunculus sessiliflorus, Stellaria flaccida, Rorippa eustylis, Pratia purpurascens, Pellaea calidirupium, Oplismenus aemulus, Lomandra multiflora, Haloragis heterophylla, Cynodon dactylon, Crinum flaccidum, Rorippa laciniata, Pellaea calidirupium, Oxalis perennans, Lepidosperma laterale, Juncus aridicola, Gonocarpus micranthus, Galium gaudichaudii, Euchiton sphaericus, Dichondra* sp. A, *Desmodium brachypodum, Cyperus gracilis, Cheilanthes sieberi, Calochlaena dubia, Asplenium flavellifolium, Ajuga australis.*

Introduced taxa: *Trifolium repens, Sonchus oleraceus, Verbena bonariensis, Stellaria media, Opuntia stricta, Cyperus eragrostis, Conyza bonariensis, Centaurium tenuiflorum, Stachys arvensis, Paronychia brasiliana, Hypochaeris radicata, Hypochaeris glabra, Cirsium vulgare, Ciclospermum leptophyllum.*

Notes & conservation status: all of this community falls within the Endangered Aquatic community in the Natural Drainage System of the Lowland Catchment of the Darling River which includes the Gwydir River from Copeton Dam downstream and incorporates the main channels and tributaries such as all natural creeks, streams and associated floodplains. This determination also encompasses deep channels, deep pool areas, suspended load depositional ‘benches’, higher floodplain ‘benches’, braided channels, gravel beds and riffle zones. Implicit in this determination is the protection of associated vegetation to enable the persistence of the aquatic community that depends upon it. This community often occurs in protected gullies with an increase in moisture availability, it often has an understorey of mesic taxa including *Alectryon subdentatus* and *Notelaea microcarpa* and in some instances these can form dense Semi-evergreen Vine Thicket stands on protected slopes immediately adjacent to the stream edge. In the lower reaches *Eucalyptus camaldulensis* (River Red Gum) occurs.

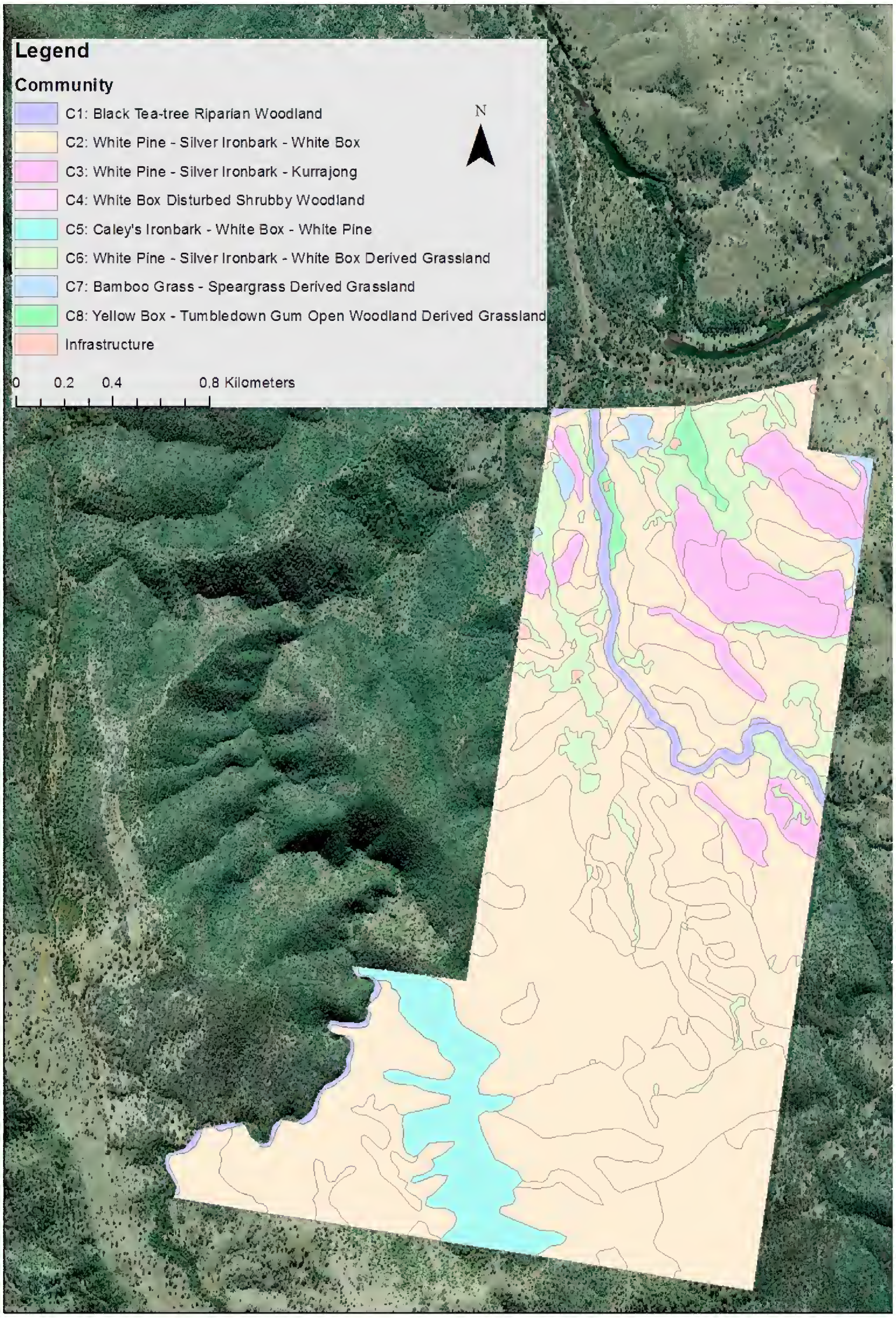
Legend
Community
C1: Black Tea-tree Riparian Woodland
C2: White Pine - Silver Ironbark - White Box
C3: White Pine - Silver Ironbark - Kurrajong
C4: White Box Disturbed Shrubby Woodland
C5: Caley's Ironbark - White Box - White Pine
C6: White Pine - Silver Ironbark - White Box Derived Grassland
C7: Bamboo Grass - Speargrass Derived Grassland
C8: Yellow Box - Tumbledown Gum Open Woodland Derived Grassland
Infrastructure
N
0
0.2
0.4
0.8 Kilometers

Fig. 3. Map of vegetation communities in the *Little Bora* Nature Conservation Trust Agreement.

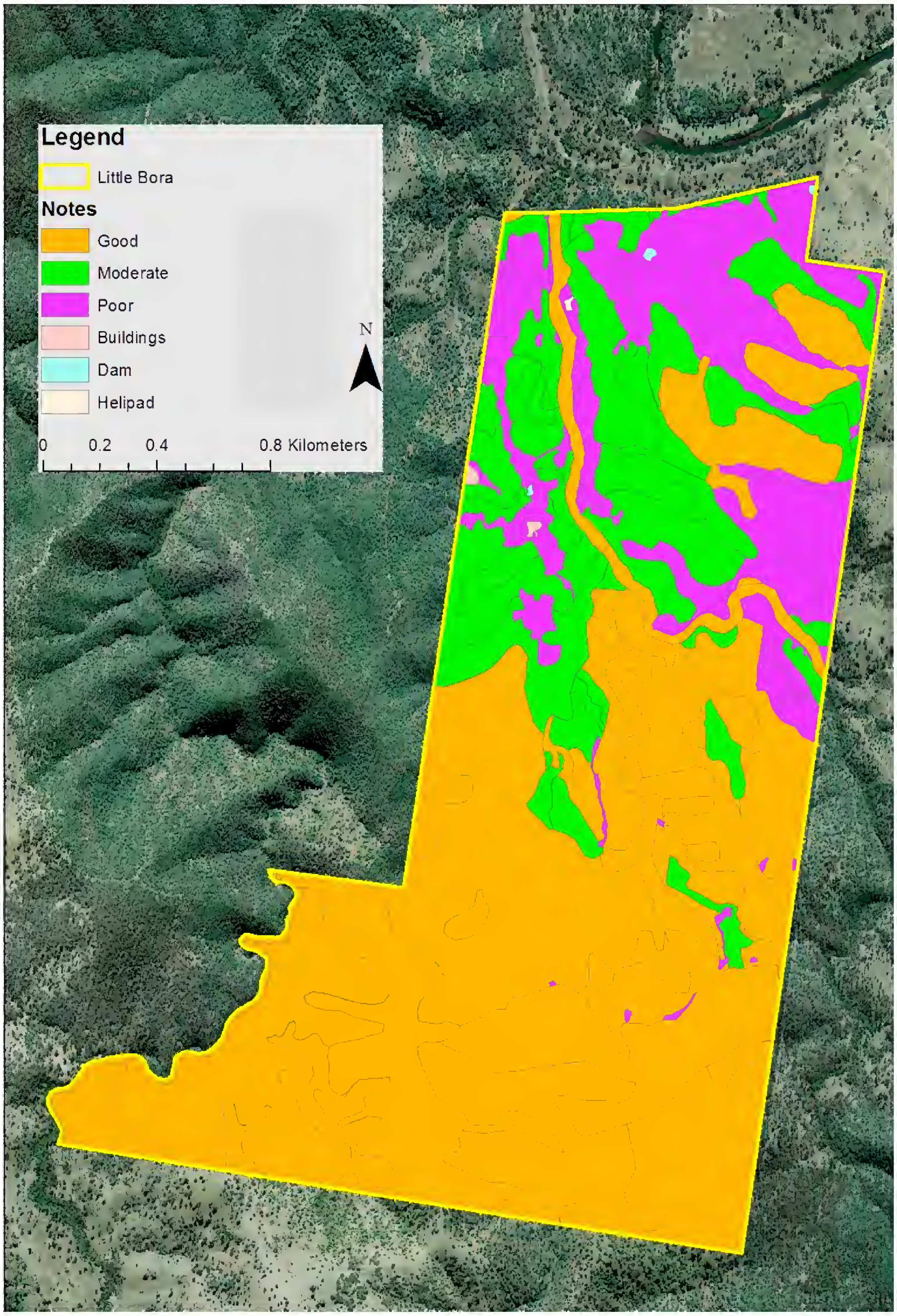

Fig. 4. Map of vegetation condition in the *Little Bora* Nature Conservation Trust Agreement.

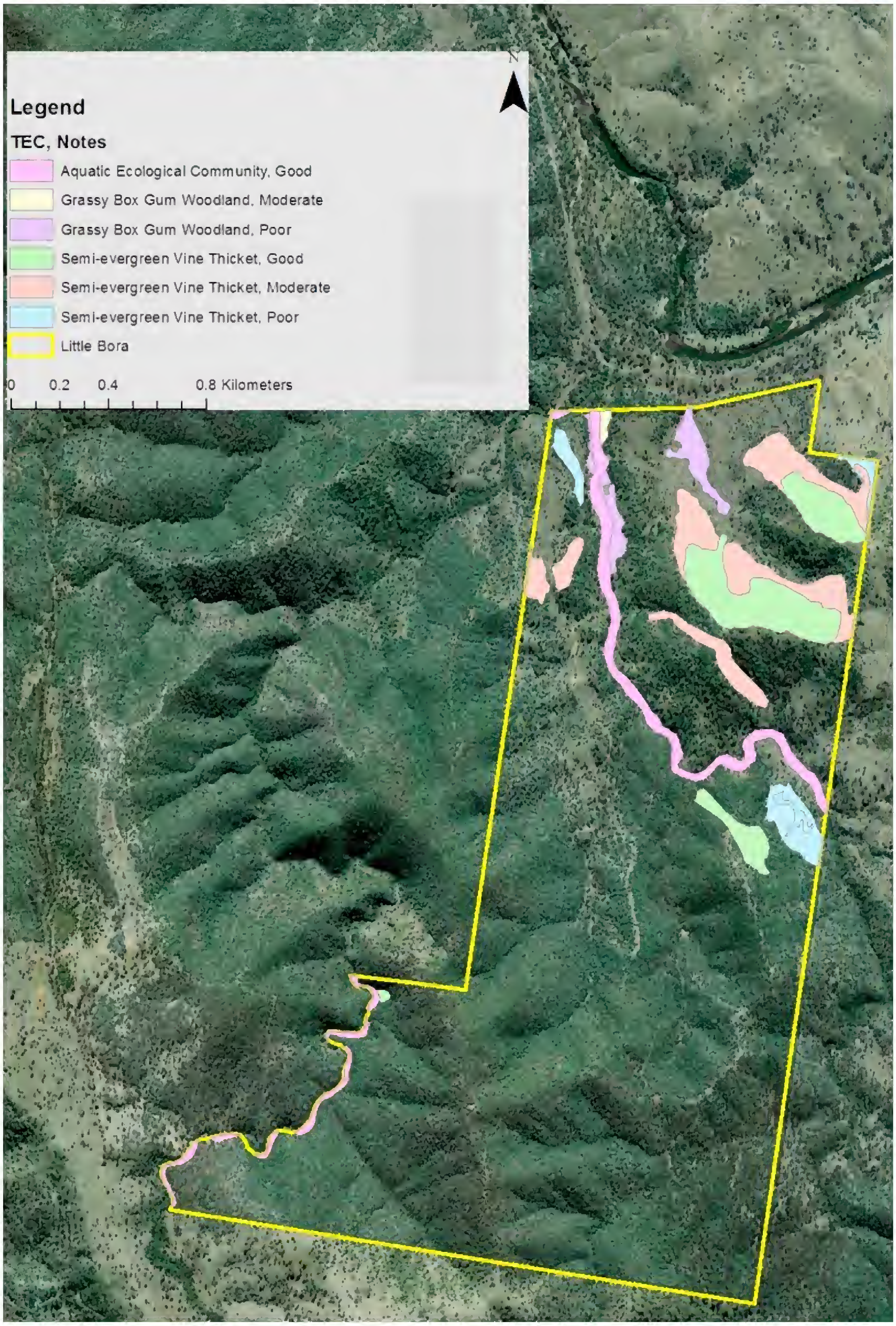
Legend
TEC, Notes
Aquatic Ecological Community, Good
Grassy Box Gum Woodland, Moderate
Grassy Box Gum Woodland, Poor
Semi-evergreen Vine Thicket, Good
Semi-evergreen Vine Thicket, Moderate
Semi-evergreen Vine Thicket, Poor
Little Bora
0 0.2 0.4 0.8 Kilometers
N

Fig. 5. Map of Threatened Ecological Communities (TECs) and their condition in the *Little Bora* Nature Conservation Trust Agreement.

Community 2: *Callitris glaucophylla* (White Cypress Pine) – *Eucalyptus melanophloia* (Silver-leaved Ironbark) – *Eucalyptus albens* (White Box) Shrubby Woodland

Structure: generally a shrubby woodland but at times a layered woodland, open woodland or grassy woodland.

Trees: *Callitris glaucophylla, Eucalyptus melanophloia, Eucalyptus albens, Eucalyptus crebra, Eucalyptus sideroxylon, Brachychiton populneus, Eucalyptus dealbata, Eucalyptus melliodora, Angophora floribunda.*

Tall shrubs: *Acacia leiocalyx, Alphitonia excelsa, Geijera parviflora.*

Shrubs: *Notelaea microcarpa, Carissa ovata, Olearia elliptica, Hibbertia obtusifolia, Pimelea neo-anglica, Solanum parvifolium, Hibiscus sturtii, Cassinia quinquefaria, Capparis mitchellii, Breynia cernua, Acacia deanei, Hibbertia riparia, Dodonaea sinuolata, Bursaria spinosa.*

Climbers & trailers: *Desmodium varians, Pandorea pandorana, Glycine tabacina, Clematis microphylla, Parsonsia eucalyptophylla, Marsdenia viridiflora, Jasminum lineare.*

Ground cover: *Aristida personata, Cymbopogon refractus, Dichondra* sp. A, *Desmodium brachypodum, Austrostipa scabra, Wahlenbergia communis, Brunoniella australis, Cheilanthes sieberi, Swainsona galegifolia, Microlaena stipoides, Eragrostis parviflora, Calotis lappulacea, Scleria mackaviensis, Lomandra multiflora, Vittadinia dissecta, Vittadinia cuneata, Galium migrans, Plantago varia, Panicum simile, Geranium solanderi, Aristida calycina, Chloris truncata, Cheilanthes distans, Sigesbeckia australiensis, Rostellularia adscendens, Hypericum gramineum, Cyperus gracilis, Bothriochloa decipiens.*

Introduced taxa: *Conyza bonariensis, Opuntia stricta, Opuntia aurantiaca, Bidens pilosa, Cirsium vulgare, Anagallis arvensis, Verbascum virgatum, Sonchus oleraceus, Plantago lanceolata, Hypochaeris radicata, Conyza sumatrensis, Abutilon theophrasti.*

Notes & conservation status: the understorey of this assemblage is reasonably stable despite some noticeable overstorey changes. The species that occur within the overstorey do not seem to form distinctive floristic groups based on analysis but are visually distinct in the field and at times can be recognised on the imagery used for mapping due to differences in crown reflectance. Thus four crown sub-community units maybe discernible and could include monodominant stands of *Eucalyptus melanophloia,* stands of *Eucalyptus crebra,* stands of *Eucalyptus albens/moluccana* and stands of *Eucalyptus sideroxylon*. However it must be emphasised that these do not represent true floristic sub-associations but only discernible overstorey units. Benson *et al.* (1996) describe this as *Eucalyptus melanophloia, Eucalyptus albens* and *Callitris glaucophylla* and its type probably restricted to the Peel and Gwydir Valleys. It is very common within the local region and is one of the dominant community types within the Bingara Community Conservation Areas (Derra Derra and Molroy) and the Gwydir River National Park (Mehi, Noonga, Murchison, Salmon, Munro), Warialda Community Conservation Reserves and within *Euroka* Nature Conservation Trust property (Hunter 2009a; 2010ab; 2011a; 2012abc). Within the Terry Hie Hie region to the west of the study area this community is also found within Bullala National Park and Irrigappa, Campbell, Montrose, Courallie, the Mission, Berrygill and Terry Hie Hie Aboriginal Areas (Hunter 2009defghi). Somewhat similar communities are known to exist at Arakoola Nature Reserve, Kwiambal National Park, Bullala National Park, Gunyerwarildi National Park and Planchonella Nature Reserve (Hunter *et al.* 1999; Hunter 2003; 2006; 2009cj). Beadle (1981) describes *Eucalyptus albens* as being particularly common on soils with a high base status particularly in calcium and generally of high fertility. *Eucalyptus sideroxylon* was also recorded within this assemblage. *Eucalyptus sideroxylon* is known from the most westerly forests within eastern Australia in a rainfall zone of 350 to 650 mm and usually occurs on soils of low fertility often sandy soils that may be surrounded by more fertile texture-contrast soils (Beadle 1980). *Eucalyptus sideroxylon* is a dominant at lower to mid altitudes within the property within the south western corner. Some very significant remnant mature stands of *Eucalyptus sideroxylon* occur. *Callitris glaucophylla* at times forms a dense and often mono-dominant canopy within this community, however recent research that includes data gathered during this current investigation shows that such dense stands only increase species density (species per site) (Hunter 2011 a; 2013a) and thus do not reduce the number of species found within a location no matter how dense the stands become.

Community 3: *Callitris glaucophylla* (White Cypress Pine) – *Eucalyptus melanophloia* (Silver-leaved Ironbark) – *Brachychiton populneus* (Kurrajong) Woodland and Semi-evergreen Vine Thicket

Structure: highly variable but often a Semi-evergreen Vine Thicket, low open shrubby woodland and shrubby woodland.

Trees: *Callitris glaucophylla, Eucalyptus melanophloia, Brachychiton populneus, Eucalyptus albens.*

Tall shrubs: *Geijera parviflora, Alphitonia excelsa, Alstonia constricta, Acacia leiocalyx.*

Shrubs: *Notelaea microcarpa, Carissa ovata, Dodonaea viscosa, Bursaria spinosa, Pimelea neo-anglica, Santalum acuminatum, Psydrax odoratum, Breynia cernua, Acacia decora, Cassinia quinquefaria, Beyeria viscosa, Abutilon oxycarpum.*

Climbers & trailers: *Clematis microphylla, Jasminum lineare, Marsdenia viridiflora, Desmodium varians, Parsonsia eucalyptophylla, Glycine microphylla.*

Ground cover: *Malvastrum coromandelianum, Bothriochloa decipiens, Aristida personata, Wahlenbergia communis, Austrostipa scabra, Swainsona galegifolia, Cymbopogon refractus, Calotis lappulacea, Paspalidium constrictum, Eragrostis parviflora, Dichondra* sp. A, *Desmodium brachypodum, Austrostipa verticillata, Vittadinia dissecta, Scleria mackaviensis, Lomandra multiflora, Glossocardia bidens, Cheilanthes sieberi, Sigesbeckia australiensis, Oxalis perennans, Geranium solanderi, Eragrostis leptostachya, Cyperus gracilis, Brunoniella australis, Ajuga australis.*

Introduced taxa: *Opuntia aurantiaca, Conyza bonariensis, Abutilon theophrasti.*

Notes & conservation status: this community in most instances would fall within the *TSC Act* determination of Semi-evergreen Vine Thicket whose characteristic species include a canopy of *Cassine australis, Geijera parviflora, Notelaea microcarpa* with an emergent overstorey of *Eucalyptus albens, Eucalyptus melanophloia* and *Callitris glaucophylla* with associated species such as *Alectryon subdentatus, Alstonia constricta, Aristida ramosa, Beyeria viscosa, Boerhavia dominii, Psydrax oleifolium, Carissa ovata, Cheilanthes sieberi, Dichondra repens, Dodonaea viscosa, Indigofera brevidens, Pandorea pandorana, Parsonsia eucalyptophylla, Phyllanthus subcrenulatus, Pimelea neo-anglica, Spartothamnella juncea* and *Thellungia advena*. Out of a these 23 characteristic species all but one were found within this community. The *TSC Act* determination is included within the Federal *EPBC* Act determination of Semi-evergreen Vine Thickets. Curran *et al.* (2008) described this community as Floristic Group 3: *Elaeodendron australe, Geijera parviflora* and *Notelaea microcarpa* and Floristic Group 5: *Notelaea microcarpa, Geijera parviflora* and *Ehretia membranifolia*. This grouping occurs predominantly within the North Western Slopes of New South Wales. Semi-evergreen vine thicket (SEVT) is a type of rainforest that occurs on the North West Slopes of New South Wales, extending north from the Liverpool Range through southern and central Queensland to areas inland of Townsville. Outliers also occur in the upper Hunter Valley of NSW, near Scone. Vine thicket has the structural (when best developed a dense, often closed canopy) and floristic (plant species composition) characteristics of rainforest, but because of its low height (generally 4–9 m) it cannot be considered to be forest (Curran, *pers. comm.*). Floyd (1990) places these communities within his Sub-alliance No. 32 *Notelaea microcarpa – Ehretia membranifolia – Geijera parviflora* for his rainforest classification of New South Wales and includes vegetation as far south as the Hunter valley and north to Toowoomba. Floyd (1990) suggests that for optimal development of this community type rainfall is around 575–650 mm.

Community 4: *Eucalyptus albens* (White Box) Disturbed Open Shrubby Woodland

Structure: a low open layered shrubby woodland.

Trees: *Eucalyptus albens.*

Shrubs: *Cryptandra amara* var. *floribunda, Notelaea microcarpa, Acacia decora, Hibbertia obtusifolia, Cassinia quinquefaria, Carissa ovata, Acacia leiocalyx.*

Climbers & trailers: *Desmodium varians, Clematis microphylla.*

Ground cover: *Cymbopogon refractus, Wahlenbergia communis, Tripogon loliiformis, Panicum simile, Oxalis perennans, Dichondra repens, Calotis lappulacea, Aristida personata, Poranthera microphylla, Oxalis chnoodes, Malvastrum coromandelianum, Lomandra multiflora, Glossocardia bidens, Geranium solanderi, Chrysocephalum semipapposum, Cheilanthes sieberi, Arthropodium milleflorum.*

Introduced taxa: *Opuntia aurantiaca, Bidens pilosa, Anagallis arvensis.*

Notes & conservation status: this is an unusual occurrence of disturbed *Eucalyptus albens* shrubby woodland and probably occurs within a transitional area between Community 3 and Community 1. Some locations just above the creek line within the far south west of the property included areas within Community 2 had an understorey with dense stands of *Cryptandra amara* on shallow soils. These natural areas were only small in extent and very sporadic in occurrence. The location of this community was within reasonable proximity to creek and on shallow soils. It is likely that it is both a disturbed and intermediate assemblage with an unusual combination of floristics.

Community 5: *Eucalyptus caleyi* subsp. *caleyi* (Caley's Ironbark) – *Eucalyptus albens* (White Box) – *Callitris glaucophylla* (White Pine) Shrubby Woodland

Structure: a shrubby woodland.

Most common natives: listed in order of decreasing summed cover scores (fidelity x cover).

Trees: *Eucalyptus caleyi, Eucalyptus albens, Callitris glaucophylla, Eucalyptus dealbata.*

Tall shrubs: *Alphitonia excelsa, Geijera parviflora, Acacia cheelii, Acacia neriifolia.*

Shrubs: *Olearia elliptica, Notelaea microcarpa, Pimelea neo-anglica, Solanum parvifolium, Spartothamnella juncea, Acacia deanei, Carissa ovata, Hibbertia obtusifolia, Bursaria spinosa, Breynia cernua.*

Climbers & trailers: *Glycine microphylla, Parsonsia eucalyptophylla, Glycine clandestina, Eustrephus latifolius, Desmodium varians.*

Ground cover: *Cymbopogon refractus, Austrostipa scabra, Dichondra* sp. A, *Desmodium brachypodum, Swainsona galegifolia, Wahlenbergia communis, Notodanthonia longifolia, Lomandra multiflora, Aristida personata, Cyperus gracilis, Cheilanthes sieberi, Brunoniella australis, Aristida jerichoensis, Vittadinia cuneata, Lepidosperma laterale, Gonocarpus elatus, Einadia nutans, Carex inversa, Aristida calycina, Sida corrugata, Senecio prenanthoides, Paspalidium constrictum, Galium migrans, Eragrostis leptostachya, Einadia hastata, Dichondra repens, Dichelachne micrantha, Cheilanthes distans, Austrostipa verticillata, Arthropodium milleflorum.*

Introduced taxa: *Opuntia aurantiaca, Opuntia stricta, Abutilon theophrasti, Bidens pilosa.*

Notes & conservation status: *Eucalyptus caleyi* communities are more typical of the higher, and therefore correspondingly often eastern parts of the Nandewars such as around Ironbark Nature Reserve (Hunter & Hunter 2003) also the western parts of the Northern Tablelands up to Sundown National Park in Queensland. The assemblage as described here appears to be introgressional and contains a number of species more common with communities of lower altitudes. The community is therefore probably somewhat intermediate between those found in higher altitude areas in the eastern Nandewars such as Horton Falls National Park (Hunter 2009k) and those more typical of this locality (Community 2) such entities are also found within Warrabah National Park (Hunter 2008) and within the nearby Molroy section of the Bingara Community Conservation Reserves (Hunter 2009l).

Community 6: *Callitris glaucophylla* (White Cypress Pine) – *Eucalyptus melanophloia* (Silver-leaved Ironbark) – *Eucalyptus albens* (White Box) Grassy Woodland & Derived Grassland

Structure: highly variable due to past clearing practices and subsequent recovery. Generally a grassland, shrubland or layered open woodland.

Trees: *Callitris glaucophylla, Eucalyptus melanophloia, Eucalyptus albens, Brachychiton populneus, Angophora floribunda, Eucalyptus moluccana, Eucalyptus dealbata.*

Tall shrubs: *Geijera parviflora, Acacia leiocalyx, Acacia implexa*

Shrubs: *Notelaea microcarpa, Carissa ovata, Maireana microphylla, Pimelea neo-anglica, Dodonaea viscosa.*

Climbers & trailers: *Desmodium varians, Parsonsia eucalyptophylla, Jasminum lineare, Glycine tabacina, Glycine microphylla, Clematis microphylla.*

Ground cover: *Cymbopogon refractus, Bothriochloa decipiens, Austrostipa scabra, Aristida personata, Geranium solanderi, Poa sieberiana, Daucus glochidiatus, Oxalis perennans, Malvastrum coromandelianum, Dichondra* sp. A, *Bothriochloa macra, Vittadinia dissecta, Eragrostis leptostachya, Rumex brownii, Cymbonotus lawsonianus, Cheilanthes sieberi, Cyperus gracilis, Carex inversa, Calotis lappulacea, Wahlenbergia communis, Lomandra filiformis, Vittadinia muelleri, Microlaena stipoides, Hydrocotyle laxiflora, Galium migrans, Desmodium brachypodum, Chrysocephalum semipapposum, Wurmbea dioica, Veronica calycina, Swainsona galegifolia, Sida corrugata, Scleranthus biflorus, Plantago varia, Parietaria debilis, Panicum simile, Lomandra multiflora, Lomandra longifolia, Juncus aridicola, Haloragis exalata, Galium gaudichaudii, Enneapogon nigricans, Einadia nutans, Dichanthium sericeum, Chrysocephalum apiculatum, Chloris truncata, Carex incomitata, Brunoniella australis, Austrostipa verticillata, Adiantum atroviride.*

Introduced taxa: *Conyza bonariensis, Bidens pilosa, Verbena bonariensis, Opuntia aurantiaca, Anagallis arvensis, Hyparrhenia hirta, Cirsium vulgare, Hypochaeris glabra, Arctotheca calendula, Verbascum thapsus, Sonchus oleraceus, Medicago polymorpha, Verbascum virgatum, Trifolium repens, Trifolium dubium, Taraxacum officinale, Stachys arvensis, Hypochaeris radicata, Gomphocarpus fruticosus, Fumaria capreolata, Centaurea melitensis.*

Notes & conservation status: this community probably is a disturbed and degraded version of Community 2 or a similar assemblage but found on lower topographic sites. In some locations it probably did contain Semi-evergreen Vine Thicket that in time may recover. Most likely it originally contained a shrub layer greater than 30% within most situations and thus unlikely to have been Grassy Box Gum Woodland. Though considered to be largely in poor condition due to the removal of overstorey and shrubby vegetation the grass and herb components of this community at the time of survey were largely native in composition. Some locations had infestations of *Hyparrhenia hirta* (Coolatai Grass) and some areas may have a seasonal flush of exotic herbaceous species later in the season.

Community 7: *Austrostipa verticillata* (Slender Bamboo Grass) – *Austrostipa scabra* (Rough Speargrass) Derived Grassland

Structure: variable depending on past clearing activities and subsequent recovery, generally a grassland, shrubland or open woodland.

Trees: *Brachychiton populneus, Eucalyptus melanophloia.*

Tall shrubs: *Geijera parviflora.*

Shrubs: *Mairena microphylla, Notelaea microcarpa, Carissa ovata, Nyssanthes diffusa, Solanum parvifolium, Oncinocalyx betchei, Acacia decora, Acacia deanei.*

Climbers & trailers: none apparent.

Ground cover: *Austrostipa verticillata, Einadia nutans, Cyperus gracilis, Austrostipa scabra, Vittadinia dissecta, Calotis lappulacea, Bothriochloa decipiens, Urtica incisa, Malvastrum coromandelianum, Geranium solanderi, Eragrostis leptostachya, Einadia hastata, Rumex brownii, Ranunculus sessiliflorus, Oxalis perennans, Dichondra* sp. A, *Cymbonotus lawsonianus, Carex breviculmis, Sigesbeckia australiensis, Rorippa eustylis, Panicum simile, Chrysocephalum semipapposum, Arthropodium* sp. A, *Aristida personata.*

Introduced taxa: *Arctotheca calendula, Anagallis arvensis, Opuntia aurantiaca, Bidens pilosa, Verbena bonariensis, Conyza bonariensis, Cirsium vulgare, Urtica urens, Marrubium vulgare, Centaurea melitensis, Abutilon theophrasti.*

Notes & conservation status: again like Community 6 this assemblage may have been derived from Community 2 but most likely is derived from Community 3. This assemblage is found primarily on ridge and hillslopes and may have contained Semi-evergreen Vine Thicket that in time could return. The notes provided for Community 6 also apply here.

Community 8: *Eucalyptus melliodora* (Yellow Box) – *Eucalyptus dealbata* (Tumbledown Gum) Open Woodland and Derived Grassland

Structure: variable due to past clearing practices and subsequent recovery but generally a grassland or open woodland.

Trees: *Eucalyptus melliodora, Eucalyptus dealbata.*

Shrubs: *Notelaea microcarpa, Acacia neriifolia.*

Climbers & trailers: none apparent.

Ground cover: *Austrostipa verticillata, Carex inversa, Bothriochloa decipiens, Daucus glochidiatus, Cyperus gracilis, Urtica incisa, Oxalis perennans, Geranium solanderi, Chrysocephalum semipapposum, Senecio quadridentatus, Rumex brownii, Cymbonotus lawsonianus, Carex incomitata.*

Introduced taxa: *Verbena bonariensis, Bidens pilosa, Conyza bonariensis, Verbascum virgatum, Marrubium vulgare, Hypochaeris glabra, Stachys arvensis, Sonchus oleraceus, Solanum nigrum, Opuntia aurantiaca, Centaurea melitensis.*

Notes & conservation status: this community is largely a derived grassland probably originally a grassy woodland type with *Eucalyptus melliodora* (Yellow Box), *Angophora floribunda* (Rough-barked Apple) with at times *Eucalyptus camaldulensis* (River Red Gum), *Eucalyptus melanophloia* (Silver-leaved Ironbark) and *Eucalyptus dealbata* (Tumbledown Gum). This community potentially had scattered shrubs but potentially could have been termed a Box Gum Grassy Woodland. The understory is largely exotic in terms of cover in some locations and with the addition of the removal of the overstory would mean that such areas fall outside of the Threatened Ecological Community (TEC) determinations of the *EPBC* or *TSC* Acts for Grassy Box Gum Woodland. Control of weeds would cause the recovered stands to fall within the TEC determinations. However there are stands that include largely native understory and also remnant trees and thus would fall within the determinations as TEC. In this broad sense this type of assemblage is common along the western side of the tablelands and along the slopes from over the Queensland border south to northern Victoria.

Threatened Ecological Communities and Species

Current methods for the circumscription of vegetation mapping units fall generally into two distinct camps; that of the mapping of pre-defined units, and the analysis and creation of specific entities based on available data. The former is not a scientific process but one that is often necessary as both landscape planning and management require a consistent set of units that can be used by all in order to enable effective cross comparison. It is important that the purposes of the investigation dictate which form of community description and mapping is the more relevant to use and even if both may be required. Within this investigation mapping polygons were assigned community names and their boundaries delineated based on explicit results from floristic analysis. Analysis of such locally collected site data reveals nuances in local species associations that are generally lost from formal descriptions of communities based on pre-determined broader geographic treatments. However there is utility in these broader formal descriptions for understanding landscape issues and for enabling others who are less familiar with the analysis methodology and results to understand contextually what the answers represent.

Pre-defined regional or statewide types are increasingly based on a broad analysis of floristic data and therefore there is an attempt to have a scientific basis underpinning the formation of these circumscribed units. This process is useful and attempts at a compromise between the two types of community delineation described above. While this is both necessary and commendable it is not a fully scientific process but only partially so. This is because the results obtained are only truly relevant, in a scientific sense, for the data available at the time, the methodology used for analysis (which may not be relevant to some projects at the scale at which the analysis was performed). Land managers necessarily need to understand that both of the methodologies outlined are not interchangeable even though there can be overlap in the general description of units and their component floras and also in the fact that each method can inform on each other. However perceived overlap in the circumscription of units should not be confused with replaceability of one form over another.

The analysis of cover/abundance scores takes into consideration all species present, the scores given to them, co-occurrence and richness. For this reason overstorey species, ones that are the most commonly seen, are only part of a defined ‘community’ or assemblage. Overstorey species can often be common across many floristic units. Furthermore the overstorey may change yet the understoreys can be largely similar (as with Community 2). In the former instance what may appear to be a similar community because it contains the same overstorey trees may have an entirely different understorey. It is important to recognise these differences as the understorey comprises most of the floristic diversity. To ignore most species in favour of a single life form (trees for instance) will severely underestimate the diversity in a landscape. Furthermore how management occurs within floristic units should be directed to the overall composition not only on one component (such as the overstorey). It is therefore highly important to recognise floristically analysed units even though reliance on overstorey dominants may be easier for non-specialist recognition. For specific purposes other forms of interpretation that rely less of floristic analysis may be useful especially when comparing data surveyed under different seasons, intensities or by a variety of methods. For example the process of relying on floristic analysis cannot be used solely to help define some highly important management units such as Threatened Ecological Communities (TECs). In general non-quantitative methods rely more arbitrary decisions and are more often than not used to assist us in delineating units that are thought to be present when statistical inference suggests otherwise.

The analysis procedure treats all species within a site as equally important. This is essential as an individual species may or may not be present at any given site due to the randomness of nature, such as opportunistic germination and establishment or localised extinction. Thus an analysis procedure may group sites even though the overstorey may contain different species as long as the majority of species and their cover within sites is largely the same. The opposite may also be true, where some generally common understorey species within a community may inexplicably be missing however the majority of other species are the same.

Unfortunately floristic analysis of locally derived data often does not correspond directly to Threatened Ecological Communities (TECs) listed on the Commonwealth *Environmental Protection and Biodiversity Act* and the New South Wales *Threatened Species Conservation Act*. In some instances a listed TEC may form part of many floristic units defined by analysis or several TECs may be defined within a single analysed floristic unit. For example derived grasslands (such as Community 7) may have originated from more than one TEC though analysis would suggest that currently they are the same unit as most of the current species are the same. As many TECs also include their derived forms it is important to map separate grassland units based the potential progenitor TEC even though at this present time there is no floristic difference. Unfortunately condition criteria are sometimes included within the delineation of TECs that cannot be incorporated in general floristic analysis, for example the method used here. As such it is nearly impossible to delineate TEC units which have condition criteria based on analysis methods. Further confusion occurs when similar TECs are listed on both the *TSC* and the *EPBC* Acts but different criteria are used to define the TEC boundaries. In addition some TECs are defined largely not on the flora contained but on their occurrence within specific environments or locations (such as certain soil types, geologies, flood levels etc). In many of these situations only a subjective approach based on the experience of the surveyor can be used in delineating mapping boundaries.

In total 66 ha of lands were found to fall within the determination of at least three TECs; Aquatic Ecological Community in the Natural Drainage System of the Lowland Catchment of the Darling River, White Box – Yellow Box – Blakely's Red Gum Grassy Woodland and Derived Native Grassland and Semi-evergreen Vine Thickets of the Brigalow Belt (North and South) and Nandewar Bioregions (Table 2). All of the Aquatic Ecological Community was considered to be in good condition, most of the Semi-evergreen vine thickets were considered to be in good to moderate condition, however almost all of the White Box – Yellow Box – Blakely's Red Gum was in poor condition.

Dodonaea stenophylla is the only species within *Little Bora* that is currently considered to be of listed conservation significance (*NSW Threatened Species Conservation* Act; profile accessed 27 Jan 2013). This species is currently listed as presumed extinct within New South Wales. However it has recently been found in large numbers within the nearby Mehi and Noonga sections of the Gwydir River Community Conservation Areas (Hunter 2010b; 2012c). While the total population within the property was not assessed it was found in a number of locations associated with Community 2 and particularly nearby and within Community 3 but not as numerous as within Mehi or Noonga.

Conclusion

Little Bora includes one species previously thought extinct, *Dodonaea stenophylla*; it is also recently known from the nearby Mehi and Noonga sections of the Gwydir River National Park (Hunter 2010b; 2012c). Despite past logging practices at least 65% of the property is considered to be in good condition and a further 19% in moderate condition with at least 12% likely to fall within one of three Threatened Ecological Communities; Aquatic Ecological Community of the Lower Darling, Semi-Evergreen Vine Thicket or Grassy Box Gum Woodlands. Thus Little Bora is a highly significant private reserve that if managed correctly will only increase in its importance in terms of preserving local flora and vegetation. The imposition of pre-defined floristic units over new data is not a scientific process and neither is the placing of analysed units into pre-determined types. The mapping of floristically analysed assemblages and the mapping of pre-determined types even if they have been derived from analysis (using other data) are different essentially methodologies done for different purposes, at a different time using different scales and should be kept separate. However each method has its utility particularly in terms of landscape planning and it is argued that one should never supersede the other. Within this paper both where necessary to fully inform on the management issues at hand. The mapping of floristically defined units based on the locally collected data is essential to properly understand the nuances of the local environment. These units are testable and provide a locally relevant hypothesis on of assemblages and species co-occurrence that can then be used to understand changes that may occur within them due to management change, changes in climate or the evolution of local entities. However management also needs to take into consideration the importance of some pre-defined types such as threatened communities. Thus both methods are probably essential, however they are different approximations of the world and despite overlap they are not the same and are not equivalent. Time and money constraints often mean that only one method can be used however it is important to be clear about when and which method is being used and what constraints this may lead to in terms of interpreting results. Despite the perceived usefulness of fitting locally defined floristic assemblages into pre-defined entities it is important that the original results of floristic analyses are kept separate and a clear distinction is maintained between the how names and types are derived.

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Appendix 1: Flora of *Little Bora* Nature Conservation Trust Agreement property.

Taxa found within the survey sites are scored according to their occurrence in each of the eight communities defined. LB1 = *Melaleuca bracteata – Eucalyptus melanophloia – Eucalyptus camaldulensis*, LB2 = *Callitris glaucophylla – Eucalyptus melanophloia – Eucalyptus albens*, LB3 = *Callitris glaucophylla – Eucalyptus melanophloia – Brachychiton populneus*, LB4 = *Eucalyptus albens*, LB5 = *Eucalyptus caleyi – Eucalyptus albens – Callitris glaucophylla*, LB6 = *Callitris glaucophylla – Eucalyptus melanophloia – Eucalyptus albens*, LB7 = *Austrostipa verticillata – Austrostipa scabra*, LB8 = *Eucalyptus melliodora – Eucalyptus dealbata*. Nomenclature follows that of PlantNET. * denotes exotic species.

Taxon	LB1	LB2	LB3	LB4	LB5	LB6	LB7	LB8
Acanthaceae		2	1		1	1		
Brunoniella australis		1	1		1	1		
Rostellularia adscendens subsp. *adscendens*		1						
Adiantaceae								
Adiantum atroviride	1					1		
Cheilanthes distans		1	1		1			
Cheilanthes sieberi subsp. *sieberi*	1	1	1	1	1	1		
Amaranthaceae								
Nyssanthes diffusa	1		1				1	
Amaryllidaceae								
Crinum flaccidum	1							
Anthericaceae								
Arthropodium milleflorum		1		1	1			
Arthropodium sp. A							1	
Laxmannia gracilis		1						
Apiaceae								
Ciclospermum leptophyllum *	1							
Daucus glochidiatus	1					1		1
Hydrocotyle laxiflora						1		
Apocynaceae								
Alstonia constricta	1	1	1					
Carissa ovata	1	1	1	1	1	1	1	
Parsonsia eucalyptophylla		1	1		1	1		
Asclepiadaceae								
Gomphocarpus fruticosus *						1		
Marsdenia viridiflora		1	1					
Aspleniaceae								
Asplenium flabellifolium	1							
Asteraceae								
Arctotheca calendula						1	1	
Bidens pilosa *	1	1		1	1	1	1	1
Calotis lappulacea		1	1	1		1	1	
Cassinia quinquefaria		1	1	1		1		
Centaurea melitensis *						1	1	1
Chrysocephalum apiculatum						1		
Chrysocephalum semipapposum				1		1	1	1
Cirsium vulgare *	1	1				1	1	
Conyza bonariensis *	1	1	1			1	1	1
Conyza sumatrensis *		1						
Cymbonotus lawsonianus		1	1			1	1	1
Euchiton gymnocephalus	1							
Glossocardia bidens		1	1	1				
Hypochaeris glabra *	1					1		1
Hypochaeris radicata *	1	1				1		
Lagenophora stipitata		1				1		
Olearia elliptica	1	1	1		1			
Olearia gravis		1						
Senecio prenanthoides		1	1		1			
Senecio quadridentatus		1				1		1
Sigesbeckia australiensis		1	1				1	
Sonchus oleraceus *	1	1				1		1
Taraxacum officinale *						1		
Vernonia cinerea var. *cinerea*		1						
Vittadinia cuneata var. *cuneata*		1	1		1	1		
Vittadinia cuneata var. *hirsuta*	1	1	1		1	1		
Vittadinia dissecta var. *hirta*		1	1			1	1	
Vittadinia muelleri		1	1			1		
Vittadinia sulcata		1						
Bignoniaceae								
Pandorea pandorana	1	1						
Brassicaceae								
Rorippa eustylis	1					1	1	
Rorippa laciniata	1					1		
Cactaceae								
Opuntia aurantiaca *		1	1	1	1	1	1	1
Opuntia stricta var. *stricta* *	1	1			1			
Campanulaceae								
Wahlenbergia communis	1	1	1	1	1	1		
Capparaceae								
Capparis mitchellii		1						
Caryophyllaceae								
Paronychia brasiliana *	1							
Scleranthus biflorus	1	1				1		
Stellaria angustifolia						1		
Stellaria flaccida	1							
Stellaria media *	1							
Celastraceae								
Cassine australis var. *angustifolia*		1						
Chenopodiaceae								
Einadia hastata		1	1		1		1	
Einadia nutans subsp. *nutans*					1	1	1	
Enchylaena tomentosa			1					
Maireana microphylla						1	1	
Chloanthaceae								
Spartothamnella juncea	1	1	1		1			
Clusiaceae								
Hypericum gramineum		1				1		

Taxon	LB1	LB2	LB3	LB4	LB5	LB6	LB7	LB8
Colchicaceae								
Wurmbea dioica subsp. *dioica*		1				1		
Convolvulaceae								
Dichondra repens	1	1		1	1			
Dichondra sp. A	1	1	1		1	1	1	
Crassulaceae								
Crassula sieberiana						1		
Cupressaceae								
Callitris glaucophylla	1	1	1		1	1		
Cyperaceae								
Carex breviculmis		1					1	
Carex incomitata	1	1				1		1
Carex inversa		1			1	1		1
Cyperus eragrostis	1							
Cyperus fulvus		1	1			1		
Cyperus gracilis	1	1	1		1	1	1	1
Lepidosperma laterale	1	1			1			
Scleria mackaviensis		1	1			1		
Dennstaedtiaceae	1							
Calochlaena dubia	1							
Dilleniaceae								
Hibbertia obtusifolia	1	1	1	1	1			
Hibbertia riparia		1						
Epacridaceae								
Melichrus urceolatus		1						
Euphorbiaceae								
Beyeria viscosa		1	1					
Breynia cernua		1	1		1			
Chamaesyce drummondii		1						
Phyllanthus subcrenulatus	1	1						
Poranthera microphylla		1		1				
Fabaceae								
Acacia cheelii					1	1		
Acacia deanei subsp. *deanei*		1			1		1	
Acacia decora		1	1	1		1	1	
Acacia implexa		1				1		
Acacia leiocalyx subsp. *leiocalyx*	1	1	1	1		1		
Acacia neriifolia		1			1	1		1
Desmodium brachypodum	1	1	1		1	1		
Desmodium varians	1	1	1	1	1	1		
Glycine clandestina					1			
Glycine microphylla	1	1	1		1	1		
Glycine tabacina	1	1				1		
Hovea lanceolata		1						
Isotropis foliosa	1	1	1					
Lotus cruentus			1					
Medicago polymorpha *						1		
Swainsona galegifolia	1	1	1		1	1		
Trifolium dubium *						1		
Trifolium repens *	1					1		
Fumariaceae								
Fumaria capreolata subsp. *capreolata* *						1		
Gentianaceae								
Centaurium tenuiflorum *	1							
Geraniaceae								
Geranium solanderi var. *solanderi*	1	1	1	1		1	1	1
Goodeniaceae								
Brunonia australis		1						
Haloragaceae								
Gonocarpus elatus					1			
Gonocarpus micranthus subsp. *micranthus*	1							
Haloragis heterophylla	1	1				1		
Haloragis serra						1		
Juncaceae								
Juncus aridicola	1					1		
Juncus remotiflorus		1						
Lamiaceae								
Ajuga australis	1	1	1					
Marrubium vulgare *							1	1
Stachys arvensis *	1					1		1
Lobeliaceae								
Isotoma axillaris		1						
Pratia purpurascens	1							
Lomandraceae								
Lomandra filiformis		1	1			1		
Lomandra longifolia		1				1		
Lomandra multiflora subsp. *multiflora*	1	1	1	1	1	1		
Loranthaceae								
Amyema pendulum subsp. *longifolium*					1			
Amyema pendulum subsp. *pendulum*						1		1
Luzuriagaceae								
Eustrephus latifolius	1				1			
Malvaceae								
Abutilon oxycarpum	1		1					
Abutilon theophrasti	1	1	1		1		1	
Abutilon tubulosum		1						
Hibiscus sturtii var. *sturtii*		1	1					
Malvastrum coromandelianum		1	1	1		1	1	
Sida corrugata		1			1	1		
Moraceae								
Ficus rubiginosa		1						
Myrtaceae								
Angophora floribunda	1	1				1		
Eucalyptus albens	1	1	1	1	1	1		
Eucalyptus caleyi subsp. *caleyi*					1			
Eucalyptus camaldulensis	1							
Eucalyptus crebra		1						
Eucalyptus dealbata	1	1			1	1		1
Eucalyptus melanophloia	1	1	1			1	1	
Eucalyptus melliodora		1						1
Eucalyptus moluccana						1		
Eucalyptus sideroxylon		1						
Melaleuca bracteata	1							
Nyctaginaceae								
Boerhavia dominii			1					

Taxon	LB1	LB2	LB3	LB4	LB5	LB6	LB7	LB8
Oleaceae								
Jasminum lineare		1	1			1		
Notelaea microcarpa var. *microcarpa*	1	1	1	1	1	1	1	1
Orchidaceae								
Cymbidium canaliculatum		1	1					
Oxalidaceae								
Oxalis chnoodes				1		1		
Oxalis perennans	1	1	1	1		1	1	1
Phormiaceae								
Dianella revoluta var. *revoluta*						1		
Pittosporaceae								
Bursaria spinosa	1	1	1		1	1		
Plantaginaceae								
Plantago debilis		1				1		
Plantago lanceolata *		1						
Plantago varia		1				1		
Poaceae								
Aristida calycina var. *praealta*		1			1			
Aristida jerichoensis var. *subspinulifera*					1			
Aristida jerichoensis var. *jerichoensis*		1						
Aristida personata		1	1	1	1	1	1	
Aristida vagans		1						
Austrodanthonia racemosa var. *obtusata*		1						
Austrodanthonia racemosa var. *racemosa*		1						
Austrostipa scabra subsp. *scabra*	1	1	1		1	1	1	
Austrostipa verticillata	1	1	1		1	1	1	1
Bothriochloa decipiens	1	1	1			1	1	1
Bothriochloa macra		1				1		
Chloris truncata	1	1				1		
Cymbopogon refractus		1	1	1	1	1		
Cynodon dactylon	1	1						
Dichanthium sericeum subsp. *sericeum*						1		
Dichelachne micrantha		1			1			
Echinopogon caespitosus var. *caespitosus*		1	1					
Enneapogon nigricans						1		
Eragrostis leptostachya		1	1		1	1	1	
Eragrostis molybdea		1						
Eragrostis parviflora		1	1					
Hyparrhenia hirta *						1		
Microlaena stipoides var. *stipoides*	1	1				1		
Oplismenus aemulus	1					1		
Panicum simile		1		1		1	1	
Paspalidium constrictum		1	1		1			
Poa sieberiana	1	1				1		
Rytidosperma longifolium		1			1			
Sporobolus creber		1						
Tripogon loliiformis				1		1		
Polygonaceae								
Rumex brownii	1	1				1	1	1
Primulaceae								
Anagallis arvensis *		1		1		1	1	

Taxon	LB1	LB2	LB3	LB4	LB5	LB6	LB7	LB8
Ranunculaceae								
Clematis microphylla var. *microphylla*		1	1	1		1		
Ranunculus sessiliflorus var. *sessiliflorus*	1					1	1	
Rhamnaceae								
Alphitonia excelsa		1	1		1			
Cryptandra amara var. *floribunda*	1	1		1				
Rosaceae								
Acaena novae-zelandiae						1		
Rubiaceae								
Galium gaudichaudii	1	1				1		
Galium migrans	1	1			1	1		
Pomax umbellata		1						
Psydrax odoratum		1	1					
Rutaceae								
Geijera parviflora	1	1	1		1	1	1	
Santalaceae								
Santalum acuminatum			1					
Sapindaceae								
Alectryon subdentatus forma *subdentatus*	1	1						
Dodonaea sinuolata subsp. *sinuolata*		1						
Dodonaea stenophylla			1					
Dodonaea viscosa subsp. *angustifolia*	1	1	1			1		
Scrophulariaceae								
Verbascum thapsus subsp. *thapsus* *						1		
Verbascum virgatum *		1				1		1
Veronica calycina		1				1		
Sinopteridaceae								
Pellaea calidirupium	1	1						
Solanaceae								
Solanum nigrum *								1
Solanum parvifolium	1	1			1	1	1	
Stackhousiaceae								
Stackhousia monogyna						1		
Stackhousia viminea		1						
Sterculiaceae								
Brachychiton populneus subsp. *populneus*		1	1			1	1	
Thymelaeaceae								
Pimelea curviflora subsp. *divergens*		1	1					
Pimelea micrantha		1						
Pimelea neo-anglica	1	1	1		1	1		
Urticaceae								
Parietaria debilis						1		
Urtica incisa	1						1	1
Urtica urens *							1	
Verbenaceae								
Oncinocalyx betchei						1	1	
Verbena bonariensis *	1	1				1	1	1
Xanthorrhoeaceae								
Xanthorrhoea johnsonii	1							
Zamiaceae								
Macrozamia diplomera	1							

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Vegetation of beach sand ridges and geomorphological processes in the valley of the Upper Myall River, NSW

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***Abstract*:** Natural vegetation of freely draining beach sand ridges in the valley of the Upper Myall River on the lower North Coast of NSW is sclerophyllous open forest or woodland. Based on previous experience on the nearby Eurunderee area, the vegetation on the sand ridges was classified into three types. These were mapped using aerial photographs and field observation. In transects, each 50 m long, the presence of species was scored in 10, 5 X 5 m quadrats. 48 such transects were used sampling all three types of vegetation on the sand ridges and also vegetation in periodically waterlogged sites adjacent to the ridges. Data from the transects, subjected to an ordination using principal components analysis, revealed clear separation between vegetation of the ridges and that of periodically waterlogged sites. In the ordination, vegetation of the ridges formed a continuum with the three types occupying characteristic parts of the continuum, reflecting their respective distributions on sands with different geomorphological histories. The most grassy, tallest forest, termed Dry Sclerophyll Forest (DSF) is on sands either recently disturbed or deposited (Holocene) or closely overlying other substrates. *Banksia serrata* occurs in DSF. The least grassy, most sclerophyllous, lowest forest or woodland, termed Dry Heath Forest (DHF), occurs on sands apparently little disturbed since they were laid down in the Pleistocene. *Banksia aemula* occurs in DHF. An intermediate forest, in which *Banksia aemula* and *Banksia serrata* occur together, Intermediate Dry Forest (IDF), is most widely found on the sand mass close to Bombah Broadwater. This sand is postulated to have been reworked during the last Glacial Period. In short, the vegetation of these sand ridges largely varies with time since they were laid down or last disturbed in a major way. Preliminary observations indicate the degree of podsolization of their soils is similarly related to this variation in time.

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Introduction

Vegetation varies with environment in space and time. This variation is not random as environments act selectively on species. How variation in vegetation arises and is maintained in the dispersal, survival and reproduction of plants can only rarely be studied directly, as, for example, in studies of Heyligers (2006 & 2009) on colonisation by vegetation of prograding dunes. On surfaces that have been vegetated for hundreds of years or longer, spatial variation of vegetation can be described in floristic and structural terms and related to environmental variation. In some cases, variation of vegetation can be related to age of land surfaces. In the Myall Lakes National Park, this has been shown by Clements (1988) on freely draining coastal sands in the Fens Embayment of Thom *et al.* (1992) and by Myerscough & Carolin (1986) in the Eurunderee Embayment. In the Eurunderee Embayment of Thom *et al.* (1992), vegetation differed on Holocene sands,

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sands laid down in the Late Glacial and on Pleistocene sands (Myerscough & Carolin 1986). Age of a surface is important in development of its soil (Jenny 1941), and, in freely draining sands, the degree of podsolization can be directly related to their age (Thompson 1981).

Preliminary observation of vegetation of freely draining coastal sands in the Upper Myall River valley indicated similar variation, even though coastal sands in the valley are basically a Pleistocene beach ridge system (Thom *et al.* 1992). This paper describes variation in vegetation on ridges of this system and the extent that it may be related to processes that may have modified them since their deposition.

Coastal sand ridges in the Upper Myall river valley are several kilometres inland from the current coastline, the furthest inland being 15–16 kilometres from the modern beach (Shepherd 1970, Thom *et al.* 1992). The ridges are higher in elevation above present mean sea level, 5.5 to 6.5 m, than other Pleistocene beach sand ridges in the region, 3 to 5 m (Thom *et al.* 1992). Since their deposition as beach ridges some 125,000 years ago, they have been affected by the Upper Myall River, which flows through them to Bombah Broadwater (Thom *et al.* 1992). They have also been affected by the Postglacial Marine Transgression, evident in deposits in Bombah Bog (Martin 1986). Bombah Bog lies on the eastern side of the river between the southern end of the Pleistocene beach ridges and a large, higher mass of sand that lies between Bombah Bog and Bombah Broadwater (Fig. 1). This large mass of sand adjacent to the lake is more complex according to Thom *et al.* (1992) than the rest of the Pleistocene beach ridges and shows some features of aeolian effects in its formation.

Vegetation of the sand ridges and of the sand mass adjacent to the lake is open-forest or woodland (*sensu* Specht 1970), and is highly sclerophyllous and fire-prone; much of it burnt between 18 and 20 September 2009. Lower lying ground in the swales between the ridges and in Bombah Bog is periodically waterlogged, and is mostly treeless and carries wet heath or swamp, both of which are also very fire-prone. The ridges and intervening lower ground and their vegetation are thus "wallum", the term used by Coaldrake (1961) and Griffith *et al.* (2003) to cover vegetation and environment of coastal lowlands of northern New South Wales and south-eastern Queensland largely deposited during the Pleistocene.

In describing variation in vegetation on freely draining sands in the Eurunderee Embayment, Myerscough & Carolin (1986) used the names Dry Sclerophyll Forest, Dry Heath Forest and Intermediate Dry Forest for forests on Holocene, Pleistocene and Late Glacial sands respectively. They are all forests whose canopy trees are sclerophyllous with an understorey of sclerophyllous shrubs, dry sclerophyll forests as defined by Beadle & Costin (1952). They all fall within Keith's (2004) Coastal Dune Dry Sclerophyll Forests. They were differentiated both structurally and florisitically. Dry Sclerophyll Forest has the tallest trees, greatest abundance of grasses, and *Banksia serrata* as characteristic tree in the sub-canopy layer of smaller trees. Dry Heath Forest has lower, more widely spaced, trees with *Banksia aemula* as its characteristic smaller tree, few grasses and the restiad *Hypolaena fastigiata* particularly abundant in its understorey; in some areas, its trees are so widely spaced that it is woodland. Intermediate Dry Forest is intermediate both structurally and floristically between Dry Heath Forest and Dry Sclerophyll Forest with both *Banksia serrata* and *Banksia aemula* occurring as small trees in it.

In this study, the forests and woodlands on freely draining sands of the Upper Myall River valley are described and mapped as Dry Sclerophyll Forest, Intermediate Dry Forest or Dry Heath Forest of Myerscough & Carolin (1986). Their relative distributions are assessed against what is known or can be deduced about processes that have affected areas of sand since its deposition by the sea. The assessment is then compared to interpretation of variation of similar vegetation elsewhere.

Study Area

Location

The study area covers the beach sands that lie in the valley of the Upper Myall River between Buladelah and the Bombah Broadwater (Fig. 1), the most southerly of the large coastal lagoons that comprise the Myall Lakes.

Sediments and their geomorphological history

The beach sands of the Upper Myall River extend up its valley about 8 km from Bombah Broadwater (Fig. 1). The valley occupies the trough of the Myall syncline (Engel 1962, Thom *et al.* 1992), following its NW-SE strike. The sides of the syncline cradle the valley between almost parallel fairly steep ridges of hills to 100 m, and the width of the valley where the sand ridges lie is about 4 km (Thom *et al.* 1992). Beside the beach sands, this part of the valley has deposits of river alluvium. The areas of sand mapped in Fig. 1 include Pleistocene beach ridges whose morphology is clearly evident on aerial photographs, intervening swampy swales, areas mapped in Thom *et al.* (1992) as transgressive dune field with swamp, and Bombah Bog. In Bombah Bog, Martin (1986) showed that, on beach sand, marine materials were deposited during the brief Post-Glacial Marine Transgression, and then lacustrine sediments and finally peat were deposited above them. Beside areas of beach sand within the valley of the Upper Myall River, also mapped in Fig. 1 are sands associated with the lake shores.

The mapping and interpretation of areas in Fig. 1 largely follow those shown in Fig. 7–16, p. 251, of Thom *et al.* (1992), but differ as follows:

Sands shown at D4 in Fig. 1 as part of the Pleistocene beach sand system are treated as a transgressive dune by Thom *et al.* (1992).

A sand ridge (Bsr) is recognised associated with the western side of Boolambayte Lake. It runs southeast from rock-based ground near Korsmans Landing to the shores of Bombah Broadwater (G8 to F11 in Fig. 1). A very small outcrop

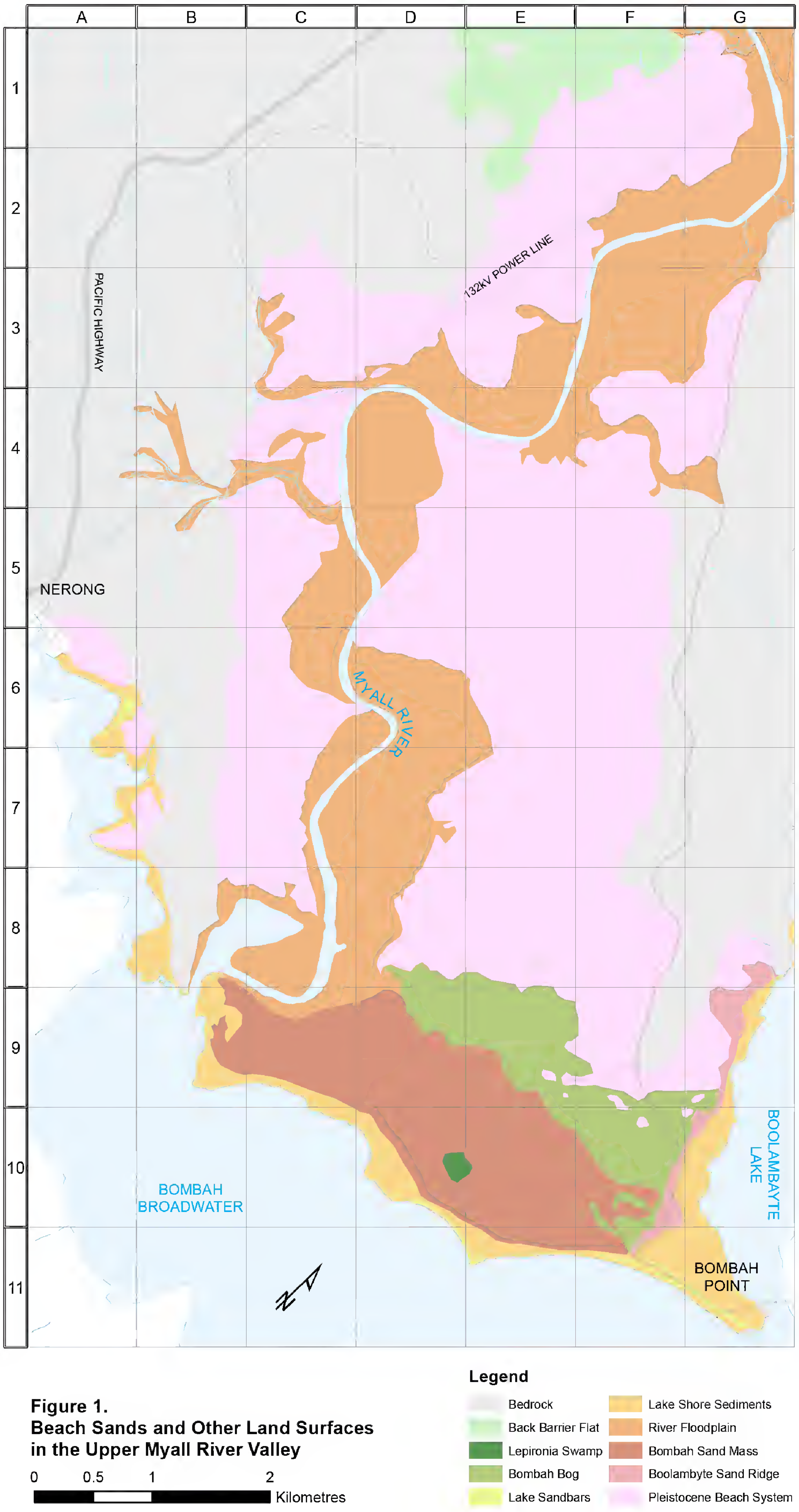

Fig. 1. Beach sands and other land surfaces in Upper Myall River valley: Bedrock (Ri); Back barrier flat (Pbf); Pleistocene beach system (Pib); Bombah sand mass (Bsm); Bombah Bog (Bb); Boolambayte sand ridge (Bsr); Lake shore sediments (Ls); Lake sand-bars (Lb); River flood plain (Fp). [Boundary between Fp and Ls (not drawn on map) arbitrarily placed at mouth of river, and extent of Fp where bounded by Ri on western part of map somewhat approximate.]

Table 1. Land surfaces in Upper Myall River valley and their characteristics

Surface	Name in Thom et al. (1992)	Characteristics	Vegetation	Similar Eurunderee area (Symbol in Myerscough & Carolin 1986)
Back barrier flat (Pbf)	Back barrier flat – Pleistocene	Low-lying, slowly draining, surface grading from sandy near, to cracking clay further from beach ridge	Wet heath	"Eastern Lagoon" (Pub)
Pleistocene beach system (Pib)	Inner Barrier strand plain – Pleistocene	Sand in beach ridges of low relief with intervening, periodocially water-logged, swales	Open-forest or woodland of eucalypts with sclerophyllous understorey on ridges; swales with wet heath or, in seepage zones, open-forest of *Eucalyptus robusta*	Differentiated Inner Barrier (Pib)
Bombah sand mass (Bsm)	Transgressive dune field – Pleistocene	Sand in long wide ridge of moderate relief with a water-filled depression.	Open-forest of eucalypts with sclerophyllous understorey, except for *Lepironia* swamp in water-filled lagoon and another swampy area	None, but some of its features are similar to Glacial dune complex (Pg)
Bombah Bog (Bb)	Generic name: Swamp – Holocene Specific site: Bombah Bog	Peat-filled depression between Pleistocene beach system and Bombah sand mass	Wet heath, and, in areas of surface drainage, open-forest of *Eucalyptus robusta*	None
Boolambayte sand ridge (Bsr)	None	Sand in ridge varying in relief from low to moderate	Open-forest of eucalypts with sclerophyllous understorey	None
Lake-influenced sediments	Freshwater swamp with Local lakeshore ridges – Holocene			
Lake shore sediments (Ls)		Mostly sands & muds below, at or slightly above mean lake water level	Mostly open-forest of paperbark and swamp oak	Lake silts and current lake shores (Ls)
Lake sand-bars (Lb)		Sand in low ridges above mean lake level freely draining	Open-forest or open-scrub	Relict sand-bars (Lb)
River floodplain (Fp)	Floodplain – Holocene	Alluvial sediment of flat to very low relief with some water-filled depressions	Open-forest to small billabongs with waterlilies or *Phragmite*s	None
Rock (Ri)	Bedrock	Gently sloping to steep hills to c. 100 m with soil mantle	Open-forest of eucalypts with mainly grassy understorey	Rock – inland (Ri)

of rock lies within it where it is closest to the current shores of Boolambayte Lake, which may have helped align the sand ridge at its formation. It was probably formed after the Postglacial Marine Transgression initiated Bombah Bog (Martin 1986). Boolambayte Lake may then have entered the Broadwater west of Bombah Point before the current lake sand bars running west from Bombah Point had formed. This sand ridge (Bsr) now divides the current lake shore sediments of Boolambayte Lake from Bombah Bog.

Bombah Bog (Bb) is bounded in the east by the sand ridge (Bsr). Bombah Bog drains south through a channel onto the shores of Bombah Broadwater. This channel, which is not mentioned in Thom *et al.* (1992), is shown as part of Bombah Bog in Fig. 1. As indicated in Fig. 1, small patches of the Pleistocene beach system are shown as remnant islands within eastern parts of Bombah Bog. At the time of the Postglacial Marine Transgression (Martin 1986), hardened coffee rock of their soil B horizon may have protected them from destruction by wave action, particularly as they are in what would have been the more protected eastern end.

The large complex sand body adjacent to the northern shores of Bombah Broadwater (Bsm) is bounded in the east by the channel draining onto the shores from Bombah Bog. Thom *et al.* (1992) show this complex body of sand running further east and north than it extends, including in it parts of the Boolambayte sand ridge (Bsr).

Table 1 gives further details of the areas mapped in Fig. 1.

Land use

Most land on the beach sands of the valley is now within Myall Lakes National Park. Broomham's (2010) history of the area that is now the park begins with the Worimi people, details European settlement and steps in formation of the present park. The national park extends up the valley from the lake to the S bend in the river at 4C–4E in Fig. 1. Most of the land north of the bend on each side of the river lies outside the national park, and is subject to various uses. This includes the most inland of the beach ridges, which was mined for rutile in the 1980s. There are also some small parcels of land on beach sand further south, at 8F in Fig. 1, that lie outside the national park, and small houses are on some of them.

Within the national park, Legge's Camp, now Myall Shores Resort, occupies two rock outcrops at Bombah Point and the sand bar that runs west along the lake shore from the southern outcrop. It has been a holiday camping area for the last hundred years (Broomham 2010). Also, on the Boolambayte sand ridge (Bsr), at 9G in Fig. 1, where a small outcrop of rock occurs, there is a patch with pines and other spp. not native to the area, presumably remains of an erstwhile garden.

On the alluvium on north-western areas mapped in Fig. 1, which lie outside the boundaries of the national park, most of the land is fenced and chiefly used for grazing cattle. Some alluvial areas within the national park were previously grazed by stock.

Some of the lower parts of the rock-based land either side of the valley have been cleared for grazing, but most of the rock-based land of the valley's sides is or has been State Forest; much of the forest on the north-western side of the valley is now part of the national park.

Methods

Data collection

Areas of freely draining sands in the valley (Fig. 2) were identified on black and white aerial photographs. The photographs were taken vertically above the land surface in the 1960s by the New South Wales Department of Lands. Each area of these sands over about a hectare was visited. Forest on it was mapped on the aerial photographs, drawing boundaries, where necessary, between Dry Sclerophyll Forest (DSF), Dry Heath Forest (DHF), or Intermediate Dry Forest (IDF). As indicated in the introduction, as in Myerscough & Carolin (1986), recognition of each of these types of forest was based on structural and floristic characteristics, the occurrence of *Banksia aemula* alone (DHF), of *Banksia serrata* alone (DSF), and co-occurrence of *Banksia aemula* and *Banksia serrata* (IDF). Vegetation on the swales between sand ridges and other periodically waterlogged areas is only represented by data from specific sites.

In 1982, floristic data were collected from 48 sites. Most sites were on freely draining sands, but some were in periodically waterlogged areas, in Wet Heath Forest (WHF), Wet Heath (WH) and Swamp (Sw), as defined in Myerscough & Carolin (1986). WH sites were in swales within the Pleistocene beach system, except for some WH sites on the Back barrier flat (Pbf). WHF sites appeared to be on ridge sites closer to the water table than other ridge sites.

Data from sites other than those with freely draining sands allowed the set of data from the ridges not only to be examined within the set but to be compared to data outside the set ("within-habitat" and "between-habitat" comparisons).

Sites were chosen to cover the ridges from north to south and east to west as well as the large sand mass adjacent to Bombah Broadwater (Bsm in Fig. 1). Location of each site (Fig. 2) was recorded on the relevant 1:25 000 topographic map. At each site, a 50-m transect was laid out, taking care that it was entirely within a single type of vegetation. Presence of species was recorded in successive 5 X 5 m quadrats along the transect, giving a maximum score of 10 for any species occurring in all the quadrats. Species of tree were recorded as present if any part of their canopy was above the quadrat and other species were recorded as present if they were rooted within the quadrat.

Boundaries between adjacent types of vegetation were also examined. Data were collected along six transects.

Four transects (T1–T4) were on the long beach ridge between D7 and F7 in Fig. 2. Three of these, T1, T2 and T3, crossed the ridge, examining change of vegetation across boundaries between freely draining sands of the ridge and adjoining periodically waterlogged areas. Relative levels of the ground surface were recorded at intervals along each transect, using a staff and an alidade. Depths to the watertable were also recorded at intervals, using an auger and allowing a short time in each hole for the water level to stabilise before measuring it. Variation in vegetation was recorded using point quadrats; contacts with a pin (c. 4.5 mm in diameter) placed every 0.5 m along the transect were recorded for common understorey spp. (those listed in Table 2 with some additional locally common spp.). Contacts were expressed over 10 m lengths of the transect (i.e. with a maximum of 20 contacts). Species of tree and larger shrub were recorded when the point quadrat was below their canopy. A more objective measure of their cover would have been the intersection of cross-wires with their canopy viewed through a moose-horn telescope (cf. Specht 2009). Their cover would have been over-estimated by simply recording being below their canopy.

In T4, along the ridge, relative levels of the surface and depths to the watertable were not measured, and contacts with understorey spp. and assessment of cover of tree and taller spp. of shrub were again made at 0.5 m intervals, but were expressed over 50 m lengths of the transects (i.e. with a maximum score of 100). The presence of additional species of trees, not "contacted" by the point quadrats, was recorded in successive 10 X 10 m quadrats along the transect, and heights of trees were subjectively estimated.

Two transect (T5 & T6) were in the Bombah sand mass (Bsm in Fig. 2 & Table 1). Along each of them, height of the ground surface above an adjacent periodically waterlogged area was recorded using a staff and alidade, and, using a hand auger, where they could be reached, depths were recorded to the watertable and soil B horizon. Along T5, data on the vegetation were collected as described for T1, T2 and T3, but also in T5 the number of trees were counted in successive 10 X 10 m quadrats along the transect.

Soils were examined in 1989 across the range of types of ridge vegetation. Nine sites were visited. In each site, within an area approximately 20 X 20 m, four holes were drilled with a hand auger until either a humus-stained B horizon or the water table was reached. In each hole, characteristics of the soil profile were noted, and samples collected of the A_1 (at 0–10 cm) and A_2 horizons (at approximately midway between the bottom of the A_1 and top of the B horizon or the watertable). In the laboratory, standard procedures of chemical analysis were used (Allen 1989). Total amounts of calcium, potassium, and magnesium in the samples were determined, digesting oven-dry soil heated in a mixture of nitric, perchloric and sulphuric acids, cooling and neutralizing the digest and then using an atomic absorption spectrophotometer to determine amounts of Ca, K and Mg. Total amounts of phosphorus in the samples were determined in the West Pennant Hills laboratory of the then Forestry Commission of N.S.W., treating soil in a muffle furnace at 550°C, extracting P in boiling hydrochloric acid, diluting the extract and then using ammonium molybdate with other reagents to determine colorimetrically amounts of P.

Analysis & presentation of data

A map of vegetation on freely draining sands in the valley and along the northern shores of Bombah Broadwater was prepared using aerial photographs and field observations onto a 1:25 000 base taken from relevant topographic maps (Fig. 3).

Plant names used are those listed with their authorities in the Royal Botanic Gardens and Domain Trust's plantnet (www.plantnet.rbgsyd.nsw.gov.au), accessed in May 2009. From the floristic data (Appendix 1), the most commonly and frequently occurring species were arranged according to their growth forms (Table 2) to facilitate floristic and structural description of the types of forest on the sand ridges.

The full floristic set of floristic data (Appendix 1) was used to explore variation in vegetation types over the sand ridges (within-habitat variation) and between vegetation of the ridges and that of nearby periodically water-logged sites in the swales and Back barrier flat (between-habitat variation). Two hypotheses were tested: (i) overall floristic differences exist between sites on freely drained sands and periodically waterlogged sites, and (ii) there is a gradient in floristic variation from Dry Sclerophyll Forest through Intermediate Dry Forest to Dry Heath Forest.

This was done by ordination, gradient analysis in the sense of ter Braak & Prentice (1988). The analysis uses scores of species within sites to assess similarities among all the sites. Two axes are extracted from the analysis that represent as much as possible of the total variation among the sites. The positions of individual sites plotted on the axes allow overall floristic variation among the sites to be assessed. The relative positions of sites in the ordination can also be explored against scores of individual species in the form of "biplots" (ter Braak & Prentice 1988). This is useful in assessing the particular association of common and frequent species of various growth forms with specific sorts of vegetation.

Three forms of ordination were tried, correspondence analysis (CA), detrended correspondence analysis (DCA) and principal component analysis (PCA). Salient features of each are described and explored by ter Braak and Prentice (1988). PCA was chosen as it gave the most readily interpreted pattern in positions of sites on the first two extracted by the analysis. In PCA, plots of sites with freely drained sands were widely spread on the second axis, while CA and DCA gave a tight clustering of these sites on both axes, showing their close similarity but almost completely masking floristic differences among them.

Results

Vegetation of freely drained sands

The vegetation of freely drained sands was mapped (Fig. 3) as Dry Sclerophyll Forest (DSF), Intermediate Dry Forest (IDF) or Dry Heath Forest (DHF), according to the occurrence of *Banksia serrata* alone (DSF), *Banksia serrata* and *Banksia aemula* together (IDF), or *Banksia aemula* alone (DHF). DHF is the most extensive, occurring over much of the area of the ridges of the Pleistocene beach system (Pib) (Figs. 1 & 3). IDF occurs extensively over the Bombah sand mass (Bsm), and in only small patches at some of the edges of the Pleistocene beach system (Pib) (Figs. 1 & 3). DSF covers the Boolambayte sand ridge (Bsr), the southern edge of Bsm, facing Bombah Broadwater, and its north-western edge, facing flood water moving down the Upper Myall River (Figs 1 & 3). On Pib, DSF is confined to areas either abutting the floodplain of the river or where sands probably shallowly overlie other substrata (Figs. 1 & 3).

Floristically, DSF, IDF and DHF are closely related (Fig. 4, Table 2). DSF and DHF form separate clusters of sites in the ordination, but IDF sites lie between them and overlap each of their clusters. In short, there is a continuum from DSF through IDF to DHF. Periodically waterlogged sites are separate from DSF, IDF and DHF on freely drained sites. Wet Heath Forest (WHF) sites, on apparently low-lying parts of beach ridges, cluster more closely to DSF, IDF and DHF than do Wet Heath (WH) sites (Transects 4, 19, 20, 23, 24, 25 & 41), which form a tight cluster on the right of the ordination diagram.

Dry Sclerophyll Forest (DSF), Intermediate Dry Forest (IDF) and Dry Heath Forest (DHF) differ structurally and floristically, though shrub species of their understoreys are fairly similar in their occurrence and frequency across them (Table 2). *Corymbia gummifera* is the most consistently and frequently occurring species of tree across the three types of forest (Table 2). *Angophora costata* has its highest frequency of occurrence in DSF, *Eucalyptus pilularis* in DSF and IDF, and *Eucalyptus signata* in DHF (Table 2, Fig. 5d).

Dry Sclerophyll Forest (DSF), in the top left of the ordination of data (Fig. 4), has high occurrence and frequency of *Banksia serrata* (Table 2, Fig. 5 (c)), *Pteridium esculentum*, *Themeda australis*, *Lomandra longifolia* and *Dianella caerulea* (Table 2, Fig. 5 (a)). Structurally, it has tall trees, 25–30 m (e.g. Table 3), and is open-forest (*sensu* Specht 1970). In contrast, Dry Heath Forest (DHF) has high occurrence and frequency of *Banksia aemula* (Table 2, Fig. 5 (c)) and *Hypolaena fastigiata* (Table 2, Fig. 5 (a)). Its trees are generally lower than those of DSF, varying from 25 to just over 10 m high (Table 3), and their cover varies such that DHF ranges structurally from open-forest to open-woodland (*sensu* Specht 1970). Some small areas within DHF are treeless and are thus Dry Heath (DH); larger patches of DH are mapped in Fig. 3, but smaller ones are not. Intermediate Dry Forest (IDF), structurally similar to DSF, has both *Banksia aemula* and *Banksia serrata*, and has relatively high occurrences of *Pteridium esculentum* and *Themeda australis* (Table 2).

Table 2. Species occurring with a frequency (Freq) > 30% (tree spp. > 20%) in one or more types of vegetation (Dry Heath Forest (DHF); Intermediate Dry Forest (IDF); Dry Sclerophyll Forest (DSF); Wet Heath Forest (WHF); Wet Heath (WH); Swamp (Sw)) and number of sites of their occurrence (No. maximum for DSF 13; IDH 5; DHF 18; WHF 4; WH 7; Sw 1).

Vegetation	**DSF**		**IDF**		**DHF**		**WHF**		**WH**		**Sw**	
	No.	**Freq**	**No.**	**Freq**	**No.**	**Freq**	**No.**	**Freq**	**No.**	**Freq**	**No.**	**Freq**
(i) Tree species												
Angophora costata	12	51	1	10	10	17	3	40	1	1		
Corymbia gummifera	13	47	5	68	17	43	2	38				
Eucalyptus pilularis	12	33	4	38	6	12						
Eucalyptus resinifera							3	33				
Eucalyptus robusta	1	1							2	11	1	40
Eucalyptus signata			1	4	12	28	1	25				
(ii) Banksia species												
Banksia aemula			5	60	18	100	1	8				
Banksia oblongifolia					3	2	2	48	4	33		
Banksia serrata	13	89	4	50								
(iii) Myrtaceous shrub spp.												
Callistemon citrinus							1	23	7	84	1	60
Leptospermum juniperinum							2	13	4	36	1	10
Leptospermum polygalifolium	2	3	1	2	13	41	4	73	4	16		
Leptospermum trinervium	5	8	5	70	15	47						
Melaleuca nodosa					6	12	2	43	2	9		
Melaleuca sieberi							4	68	4	50		
Melaleuca thymifolia							3	18	7	77		
(iv) Other shrub species												
Acacia suaveolens	10	32	5	40	11	17	1	3				
Acacia ulicifolia	13	41	5	56	13	29	2	30				
Bossiaea heterophylla	11	52	5	90	18	67						
Bossiaea rhombifolia	9	47	3	14	1	1						
Brachyloma daphnoides	5	15	4	56	12	22						
Dillwynia glaberrima	2	2	1	2	14	35						
Dillwynia retorta	6	20	5	70	11	23	2	38				
Eriostemon australasius	5	20	5	76	18	59						
Gompholobium virgatum	3	15	4	38	11	13						
Gonocarpus teucrioides	13	47	5	44	8	17	2	15				
Hibbertia fasciculata	2	2			12	34	1	5				
Hibbertia obtusifolia	13	72	5	76	13	39	1	3				
Leucopogon ericoides	5	13	4	56	8	11						
Leucopogon parviflorus	4	4	3	16	13	34			1	1		
Leucopogon virgatus	8	19	5	48	10	28						
Monotoca scoparia	5	5	3	12	16	46	1	3				
Phyllota phylicoides	3	9	4	44	10	18						
Pimelea linifolia	4	7	3	32	13	31	2	18	1	1		
Platysace linearifolia	7	35	4	44	16	53						
Ricinocarpos pinifolius	10	45	4	66	18	73						
Zieria laevigata			1	2	14	31	1	8				
(v) Pteridophytes												
Blechnum cartilagineum											1	30
Pteridium esculentum	13	100	5	98	13	60	1	8	1	6		
Selaginella uliginosa	1	1			6	13	3	20	6	33		
(vi) Grasses & lilies												
Dianella caerulea	13	45	3	12	5	3	2	5	1	1		
Entolasia stricta							3	30	6	44		
Imperata cylindrica	9	53	1	4			1	10				
Panicum simile	12	55	2	28	12	23	4	63	3	6		
Themeda australis	13	71	5	68	6	16	2	25	1	1		
(vii) Restiads, sedges & lomandra												
Baloskion pallens					6	17			4	24	1	100
Baumea arthrophylla									2	7	1	60
Chorizandra sphaerocephala									7	51	1	20
Hypolaena fastigiata	5	25	4	70	18	89	1	10				
Lepidosperma filiforme											1	90
Leptocarpus tenax					8	12	2	40	7	50		
Lomandra glauca	13	45	4	30	16	39	2	18				
Lomandra longifolia	13	76	4	52	10	32	2	45				
Ptilothrix deusta							3	48	1	6		
Schoenus brevifolius							2	40	7	91		
Sporadanthus interruptus					9	14	1	8	4	36		
(viii) Subshrub & herbs												
Pomax umbellata	12	53	4	34	5	8	1	8				
Trachymene incisa	9	22	4	22	6	19	2	38				
Villarsia exaltata									4	11	1	70
(ix) Xanthorrhoea												
Xanthorrhoea fulva							1	3	6	34		
Xanthorrhoea glauca	9	25	4	34	11	14.	1	25	1	1		

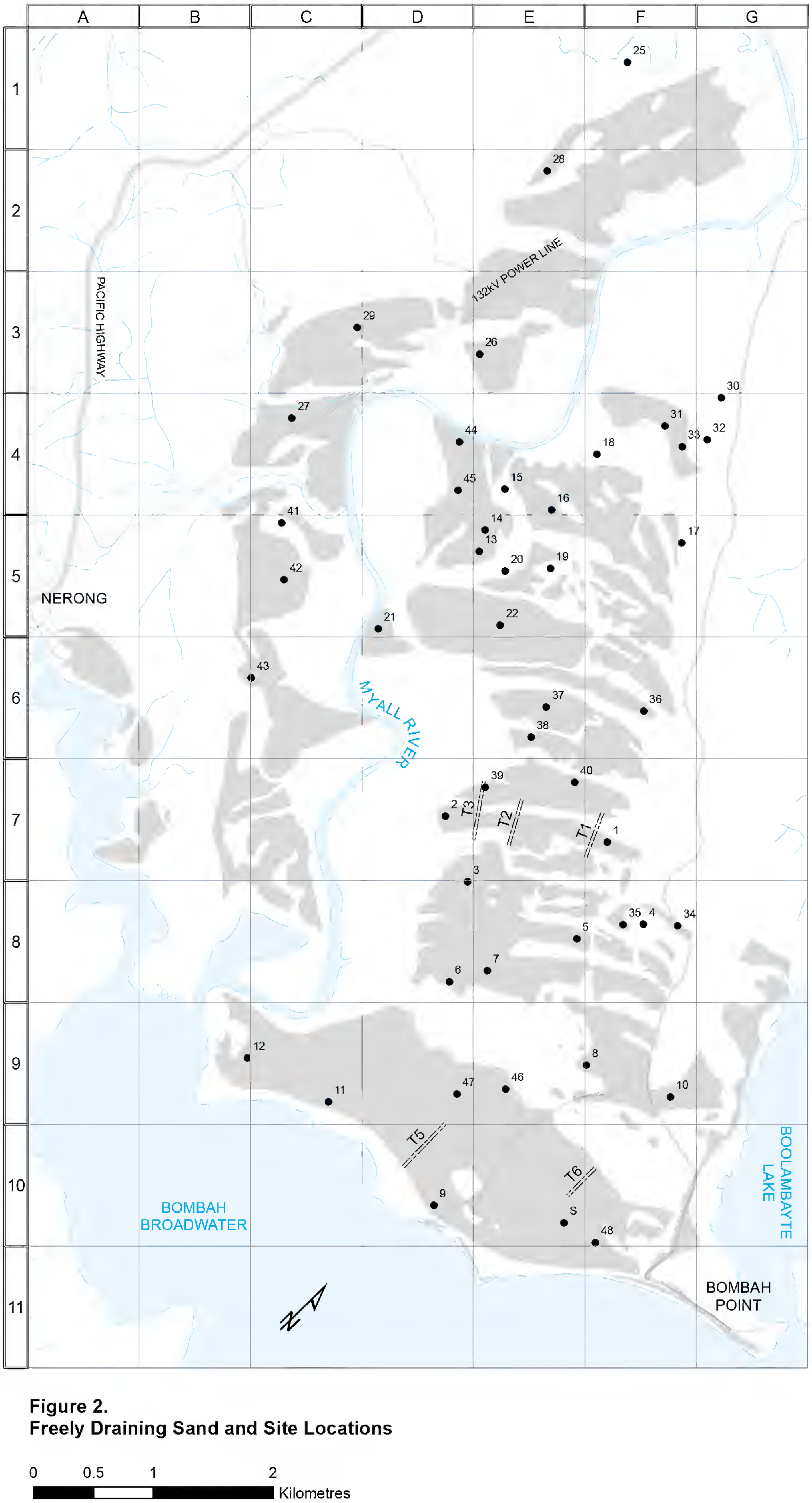

Fig. 2. Location in Upper Myall River valley of freely draining surfaces on sand (shaded grey), 48 sites (•) where floristic data were collected (soil samples collected at Sites 16, 21, 22, 27, 28, 31, 35, 42 & S (soil sampled only)) and long transects (straight lines) across vegetation boundaries along which floristic variation was recorded (T1, T2, T3, T5 & T6; T4 ran along the ridge intersected by T1, T2 & T3). Sites 23 & 24 lie just beyond the upper boundary of the map (Their grid references are given in Appendix 1).

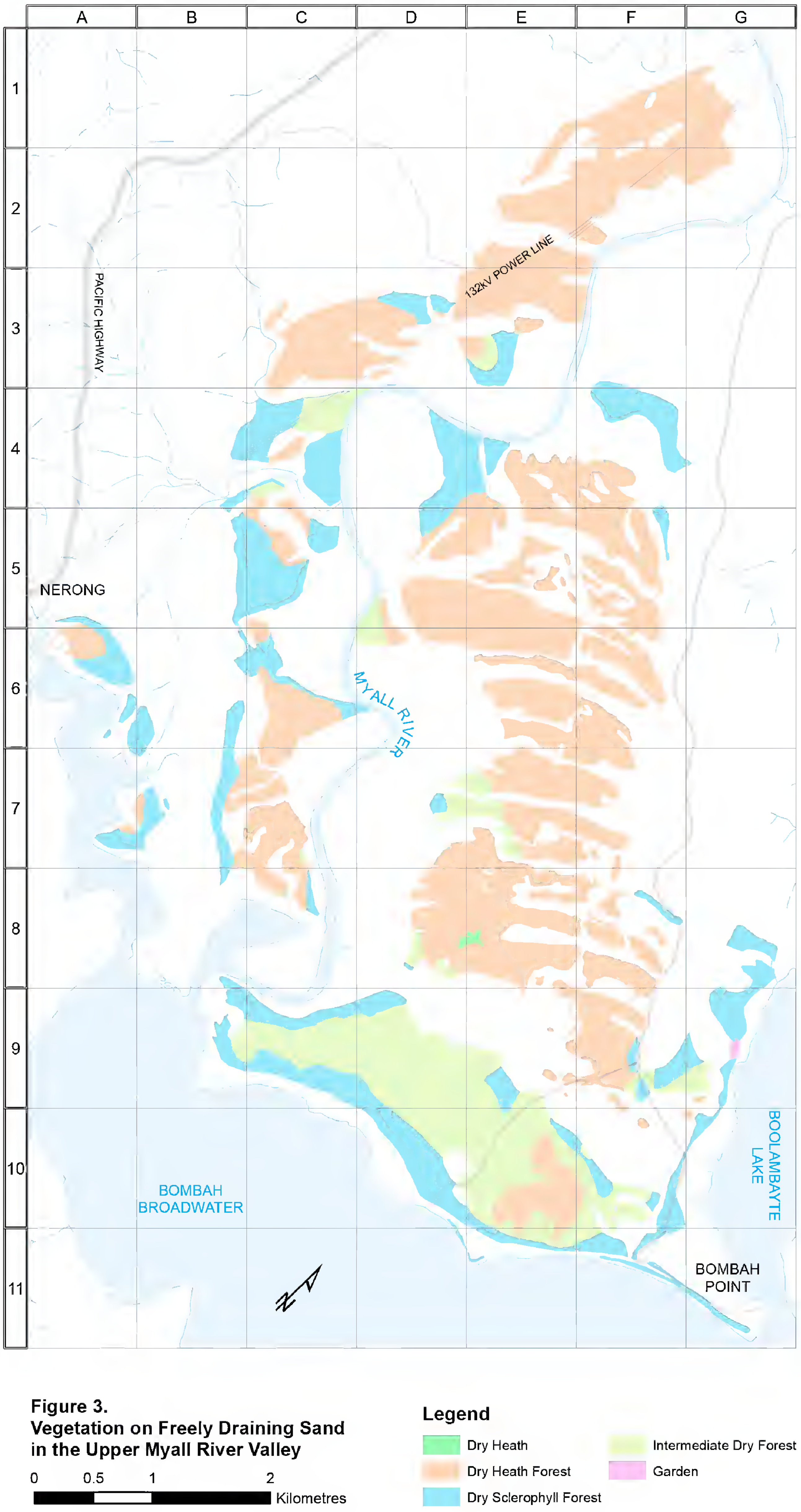

Fig. 3. Vegetation in Upper Myall River valley on freely draining sands: Dry Sclerophyll Forest (DSF); Dry Heath Forest (DHF); Intermediate Dry Forest (IDF); Dry Heath (DH); old garden.

Table 3. Transect 4: species cover (%) over 50 m lengths, presence (*) only in 10X50 m quadrats for trees, and 5X50 m for other species); spp. shown listed in Table 2 + Macrozamia communis.

Vegetation boundary	**DSF**		**DSF**	**IDF**							**IDF**	**DHF**						
Distance (m)	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**550**	**600**	**650**	**700**	**750**	**800**	**850**	**900**
Tallest tree height (m)	**25**	**30**	**26**	**22**	**24**	**24**	**24**	**23**	**20**	**22**	**21**	**24**	**25**	**23**	**12**	**20**	**17**	**12**
(i) Tree species																		
Angophora costata												*	6	*	*	12		10
Corymbia gummifera	16	24	31	*	1	19	29	34	4	24	4	*		*	*		24	
Eucalyptus pilularis	41	43	3	41	36	19	10	28	36	25	24	30	18	26				
Eucalyptus signata																		
(ii) Banksia species																		
Banksia aemula				14	1	9	*	26	19	2	15	7	23	8	26	15	1	15
Banksia oblongifolia																		
Banksia serrata	2	11	10	7	2	*	25	*	*	8	*							
(iii) Leptospermum & Melaleuca spp.																		
Leptospermum polygalifolium																4	1	
Leptospermum trinervium	1		2	7	*	12	6	2	18	15	12	8	9	9	3	11	4	3
Melaleuca nodosa																		
(iv) Shrub species																		
Acacia suaveolens	1	*	*	1	*	*	1	1	*	*	2	7	3	*	*		*	
Acacia ulicifolia	*	*	*	2	3	3	*	1	4	3	*	2	3	1	3	*	3	*
Bossiaea heterophylla	2	14	13	20	11	9	14	8	12	11	13	14	21	2	3	1	1	8
Bossiaea rhombifolia	3	4	4	1	10	2	3	11	2	6	*	*						
Brachyloma daphnoides	*	3	13	4	11	6	2	*	10	4	5	5	3	9	3	*	5	*
Dillwynia glaberrima			2	*	*	2	*	*	3	2	6	*	2	5	4	13	2	9
Dillwynia retorta		1	*	*	*	*		*	*	*	*	2	*	1	1	1	5	1
Eriostemon australasius	4		*	5	*	8	1	*	5	1	4	3	6	5	7	2	1	*
Gompholobium virgatum										2								
Gonocarpus teucrioides	6	2	2	2	*	2	2	2	4	6	*	1	7	*	*		*	1
Hibbertia fasciculata													1		5	3	4	1
Hibbertia obtusifolia	8	13	2	15	4	6	11	5	8	5	4	3	9	*				1
Leucopogon ericoides	*			*	*	*					*	*	*	*	2	13	10	3
Leucopogon parviflorus	3		*	*	*		1	*	2	4	2	1	*			*		
Leucopogon virgatus	1	1	*	1	1	*	*	*	3	4	5	1	1	3	4	*	*	1
Monotoca scoparia				*	*	2	3	*	2	*	1	2	6	9	7	1	1	*
Phyllota phylicoides										3	*	8	24	*	*		1	
Pimelea linifolia				2		2	*	*	6	*	*	*	2	1	1	3	*	4
Platysace linearifolia	18	16	20	11	14	6	24	10	16	8	7	5	21	9				2
Ricinocarpos pinifolius	*	21	10	9	5	13	14	3	9	7	3	8	10	18	2	6	2	4
Zieria laevigata												*	2	2	1	4	3	2
(v) Pteridophytes																		
Pteridium esculentum	31	20	6	11	13	12	12	7	4	5	5	9	13	*			1	1
Selaginella uliginosa																		
(vi) Grasses & lilies																		
Dianella caerulea	24	1	4	3	*	*	*	*	1	*	*	*	*	*				*
Entolasia stricta																		
Imperata cylindrica																		
Panicum simile	5	2	*	4	4	3	4	4	*	3	4	5	6	3	1	*	*	3
Themeda australis	5	12	10	6	24	8	14	13	8	12	4	1	11	3	1			
(vii) Restiads, sedges & lomandra																		
Baloskion pallens																		
Hypolaena fastigiata					6	1		25	26	48	27	42	66	37	81	81	79	77
Lomandra glauca	*	*	3	2	1	*	6	2	*	*	*	*	5	1	*	4	2	2
Lomandra longifolia	14	36	10	13	14	4	8	3	1	1	*	1	2	1				*
Schoenus brevifolius																		
Sporadanthus interruptus																		
(viii) Subshrub & herbs																		
Pomax umbellata	3	4	1	6	7	7	10	7	1	3	3	3	4	*		*	*	1
Trachymene incisa																3	*	4
(ix) Xanthorrhoea																		
Xanthorrhoea fulva																		
Xanthorrhoea glauca	*			4	*		5			4	6	7	*	2	12		*	2
(x) Cycad																		
Macrozamia communis	25	26	1	5	6	*	*				*							
Bare ground	**6**	**2**	**15**	**2**	**16**	**11**	**9**	**1**	**3**	**7**	**12**	**9**	**2**	**8**	**3**	**7**	**4**	**4**

																		DHF	
950	**1000**	**1050**	**1100**	**1150**	**1200**	**1250**	**1300**	**1350**	**1400**	**1450**	**1500**	**1550**	**1600**	**1650**	**1700**	**1750**	**1800**	**1850**	
16	**13**	**22**	**24**	**21**	**17**	**18**	**21**	**15**	**18**	**18**	**16**	**15**	**16**	**12**	**18**	**15**	**16**	**22**	**Total cover score**
14	7	20	11	8	38	8	24	32	31	21	3	12	*		10	*	*	30	297
	*	*	25	7	*	6	15	10	13	5		*		*	*	3	30	2	326
																			380
*			17	*	*	*			12	*	41		46	11	16			8	151
8	24	13	10	18	16	17	8	12	7	20	26	24	24	47	13	5	11	21	505
													1						1
																			65
				1	21	*			*	*	8	16	24	21	25	24	5		150
*	2	*	*		*	*	5	*	*	*	*	2	*	*	6	6	3	7	153
					1						17	11	2	1	2	7	*		41
	1	*	3	*		1	*			*	*							*	21
*	1	*	2	*	2	*	*	*	*	*	*	*	*	1	*	1	*	1	36
5	7	4	4	4	5	15	1	1	2	3	1			*		1	3	4	237
																			46
2	*	1	*		*		2	*	*	*	*						*	*	88
9	1	*	4	10	19	*	*		3	4	7	3	3	6	4	6	*		129
3	1	*	1	*	1	2	7	*	2	1	2	*	1	*			1	7	41
*	*	*	*	*	5	*	1	*	2	1	*	*	*			1	*	*	62
																			2
*	*	*	*	1	*	1	*	3	6	*	1			*				1	50
1	1	*	1	3	5	6	*	1	2	6	9	5	*	1	1	1	3	*	60
			*	*		*	*	*											94
5	6	*	*	*		2			*	*	*								41
*		2	*		3	*		*				*	1	2	5	6	3	*	35
*	1	*	1				3	1	1	*						1	1	*	35
2	*	1	*	*	1	2	2	*	*	1	1	1	*	*	*	2	*		47
	5	9	*	6	1							*		2					59
*	*	*	*	8	3	4	3	5	3	5	7	4	*	1		*	1	*	65
1				10	17	5	*			*	12	5	8	15	5	7	7		279
1	7	4	2	14	21	3	3	1	3	3	*	1	2	1	2	4	12	*	228
1	3	4	*	2	*	*	*	*	*	*	1	*	1	2	*	3	1	3	35
1	1	6	3	3	5	5	2	1	2	3						*	1	6	189
												2	*	3	3	2	*		10
					*	*	*												33
																		7	7
																		6	6
2	1	2	3	3	*	3	1	*	*	*	*						1	16	83
																		1	133
											7	26	17	37	35	20	*		142
80	65	66	66	74	59	76	67	70	67	82	40	66	63	62	45	60	41	41	1786
*	2	*	1	2	2	*	*	*	*		3	2	*	1	4	2	*	*	47
*		*	1	2	1		1											10	123
																		10	10
															10	6			16
1	*		2	*					3									21	87
11	4	7	3	3	5	4	1	*	3	*	*						1		49
											1		1						2
	*	*				*		*	*	5		7	*	*	1	1	*		56
																			63
6	**15**	**13**	**5**	**4**	**3**	**9**	**7**	**7**	**13**	**3**	**2**	**3**	**7**	**6**	**5**	**2**	**11**	**2**	**244**

Table 4. Soil profiles of 9 ridge sites based on four holes per site; Veg, vegetation type; A_1 horizon sampled at 0–10 cm deep; other horizons (depth to top), Wt, watertable.

Site	**27**	**31**	**42**	**21**	**S**	**6**	**22**	**28**	**35**
Veg	DSF	DSF	DSF	IDF	DHF	DHF	DHF	DHF	DHF
A_1	Dark humus-rich	Dark humus-rich	Burnt much charcoal	Dark humus-rich	Dark humus-rich	Dark humus-rich	Dark humus-rich	Dark humus-rich	Dark humus-rich
A_2	Bleached (0.7–1.1 m)	Yellow – bleached (30–80 cm)	Bleached (1.0 –1.3 m)	Bleached (1.3–1.4 m)	Bleached (0.8–1.2 m)	Light brown – bleached (45–70 cm)	Bleached (1.2–1.3 m)	Grey (55–80 cm)	Light brown – bleached (0.9–1.1 m)
B	Dark to light brown mottled slightly hardened (0.9–1.4 m)	Light brown mottled soft (0.5–1.0 m)	Black slightly indurated (2.3–2.9 m)	Very dark brown indurated (2.3–2.7 m)	(Not reached before watertable)	Dark brown, indurated mat of roots at its top (60–90 cm)	(Not reached before watertable)	(Not reached before watertable)	(Not reached before watertable)
Wt					(c. 3.1 m)	(c.1.4 m)	(c. 2.3 m)	(c.1.2 m)	(c. 1.4 m)

Table 5. Mean (SE) total calcium (Ca), potassium (K), magnesium (Mg) and phosphorus (P) in A1 and A2 horizons in soils of 9 sites (p.p.m. by weight in oven-dry soil)

Site	**27**	**31**	**42**	**21**	**S**	**16**	**22**	**28**	**35**
Veg type	**DSF**	**DSF**	**DSF**	**IDF**	**DHF**	**DHF**	**DHF**	**DHF**	**DHF**
A1									
Ca	219	166	426	386	351	125	434	143	106
	29	17	132	77	68	62	147	56	5
K	58	183	76	45	52	84	78	80	37
	6	13	12	8	13	31	12	7	4
Mg	66	92	179	70	142	102	124	87	39
	16	17	46	15	16	52	21	16	5
P	16	20	16	16	16	21	17	19	15
	0	2	3	2	2	7	2	2	2
A2									
Ca	0	25.6	0	0	0	0	0.6	0	0
	0	4.9	0	0	0	0	0.6	0	0
K	3.7	148.7	2	0	0	0.3	0	0	0
	1.1	33.5	0.7	0	0	0.3	0	0	0
Mg	0	37.2	0	1.3	0	0.4	3.9	3.8	7.7
	0	8.6	0	1.1	0	0.4	2.3	1.9	3.2
P	3.3	8.5	2	2.3	2.3	3.5	2	3.3	4.3
	0.3	0.9	0	0.3	0.3	0.3	0	0.3	0.9

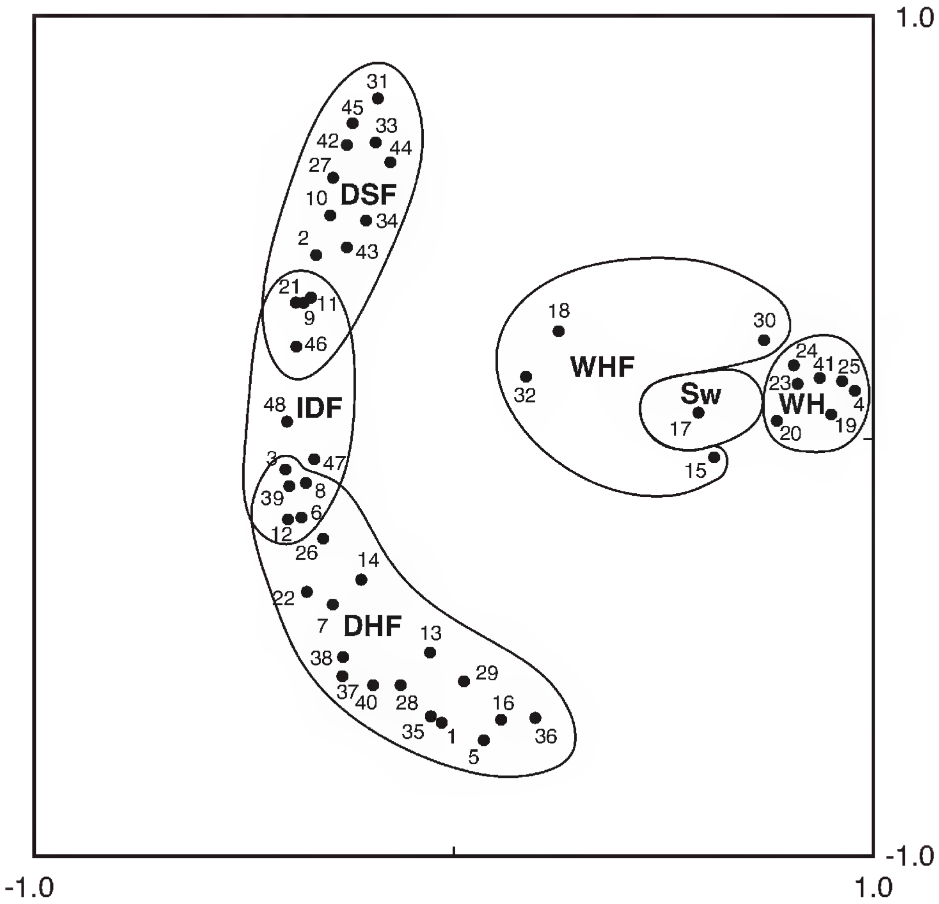

Fig. 4. Ordination of floristic data from 48 transects on the first two axes extracted from a principal components analysis. Numbers indicate the individual transects, and boundaries enclose transects assigned to Dry Sclerophyll Forest (DSF), Intermediate Dry Forest (IDF), Dry Heath Forest (DHF), Wet Heath Forest (WHF), Wet Heath (WH), and Swamp (Sw).

Soils and vegetation

In all nine sites investigated, the soils were podzols. In the three DSF soils, the B horizons were shallower and less indurated than in other sites where the B horizon was reached, and it was also above the watertable (Table 4). In all five DHF sites, the watertable was reached before the B horizon; in four sites, a B horizon was not reached.

In soils of all nine sites levels of Ca, K, Mg and P decreased markedly from the A$_1$ to the A$_2$ horizon (Table 5). In the A$_1$ horizon, sites differed in levels of each of the four nutrients, but the differences are not associated with types of vegetation carried by the sites. Site 31 had much higher levels of nutrients than the other sites. Site 31 appears to be on sand thinly overlying other sediments. The A$_2$ horizon of its soil, shallow and yellow-bleached, clearly differs from the A$_2$ horizons of the soils of the other sites, and may contain material other than just beach sand.

Vegetation and local variation

Observations at specific locations on long transects (Tables 3, 6 & 7, Appendices 2, 3 & 4) illustrate structural and floristic variation between DSF and IDF, and IDF and DHF (see particularly Table 3), and confirm that DSF, IDF and DHF occur on better drained sands than surrounding lower surfaces.

Such less well drained surfaces carry vegetation ranging from Wet Heath on sands with water tables only slightly higher than on adjoining sand ridges, to incised drainage channels with *Eucalyptus robusta* Swamp Forest, to open water with *Phragmites australis*. This is illustrated along Long Transects 1, 2 and 3 (Appendices 2, 3 & 4) that intersected the 1.8 km sand ridge along which Long Transect 4 ran (Table 3). The most easterly, Transect 1 (App. 2) crossed Wet Heath at 40–70 m and 250–320 m where the watertable was only 10–40 cm higher than on adjoining ridges carrying DHF. The

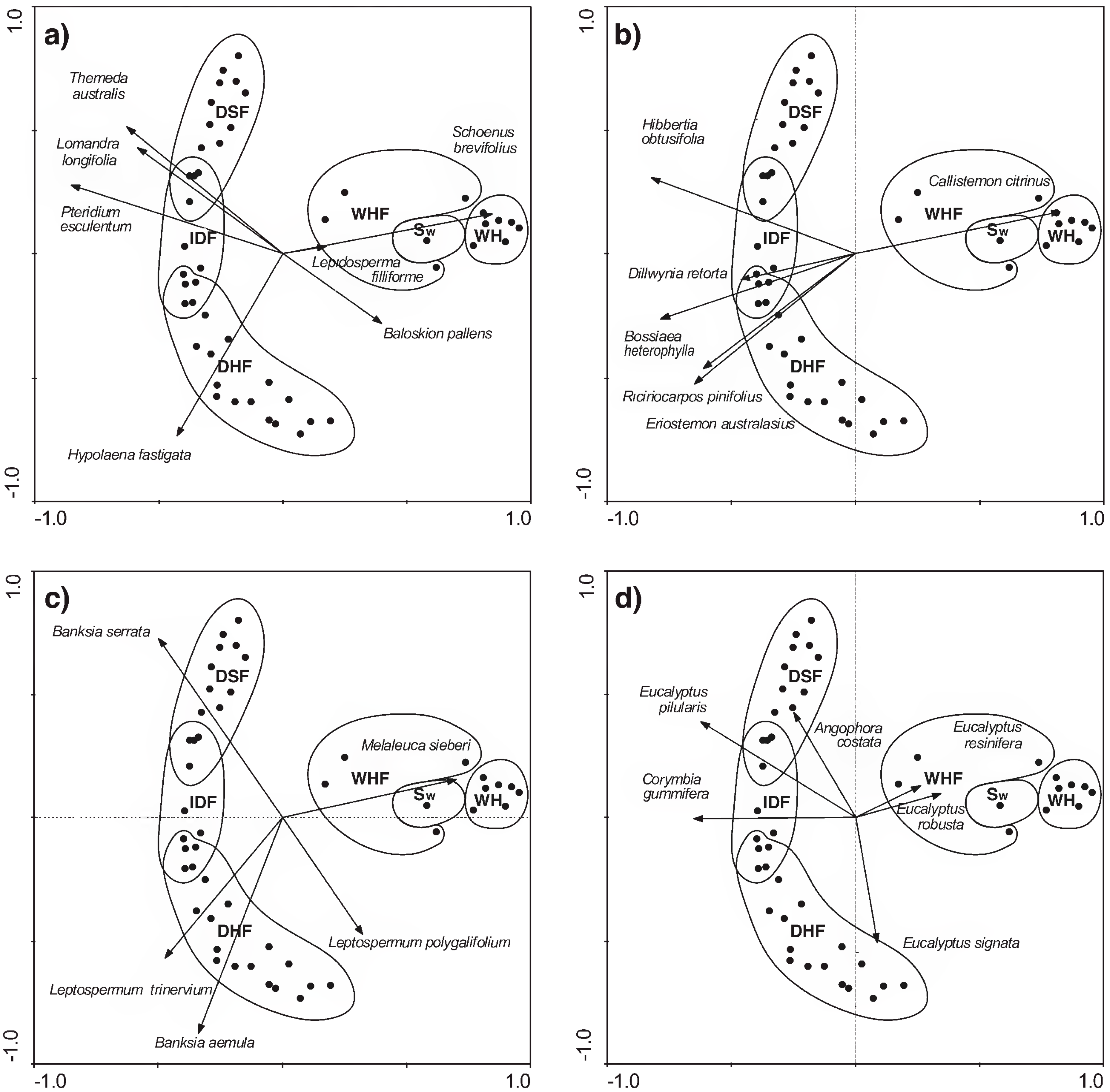

Fig. 5. "Biplots" of scores of more frequent species on the ordination of transects given in Fig. 4. (a) Bracken, *Themeda* , restiads & sedges; (b) small shrubs: (c) banksias and ti trees; and (d) trees.

Table 6. Transect 5 (bearing 360 degrees): species cover over 10 m length (max. score 20); species shown listed in Table 2 + Xylomelum pyriforme & Baloskion tetraphyllum.

Distance (m)	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**230**	**240**
Height of surface (m)	**0.9**	**2.4**	**7**	**10.9**	**12.6**	**12.6**	**12**	**11.9**	**10.5**	**9.1**	**7.7**	**7**	**6.6**	**6.5**	**6.4**	**6.5**	**6.5**	**6.5**	**6.6**	**6.6**	**6.7**	**6.6**	**6.6**	**6.5**
Depth to B horizon (m)	**1.3**	**1.9**	**1.2**	**2.2**	**3.3**	**2.4**	**3**	**2.5**	**2.6**	**>4**	**>4**	**>4**		**>4**		**>4**		**1**		**1.8**		**1.6**		**1.8**
No. of canopy & sub-canopy trees per 100 sqm:																								
Angophora costata			2		1	1	1	1		1	1			1	1	1				1		1		
Banksia aemula																								
B.aemula >3m high																								
Banksia serrata	4	14	10	3	7	6	7	16	14	13	7	5	4	13	6	7	8	6	5	10	7		3	1
B.serrata >3m high		1			1	1	1	1	1	1		1	1	2	1			5	2	1	2		1	
Corymbia gummifera				4		1						1				1	3	1	1	1		2	2	
Eucalyptus pilularis			2								1		2		1	1	1		1	1	1			
Eucalyptus signata																								
Xylomelum pyriforme																								
(i) Tree species																								
Angophora costata	8	17	14		11	20	15	18	15	20	19	20	5		8	17	19					8		
Corymbia gummifera			7	16	9						3	2		17				16	18	12		8	20	5
Eucalyptus pilularis			2	2									16	19	8		5	10		11	14	10		13
Eucalyptus robusta	15																							
Eucalyptus signata																								
(ii) Banksia species																								
Banksia aemula																								
Banksia serrata			1				1				1	3	11	3	11	1		2	7		3			
(iii) Myrtaceous shrub spp.																								
Leptospermum juniperinum	1																							
Leptospermum trinervium					1												1							
(iv) Other shrub species																								
Acacia suaveolens								1											1	1			2	
Acacia ulicifolia	5	1	2		1						6	1	3	4	2			2	2		2			2
Bossiaea heterophylla							2	1	2	2	1													
Bossiaea rhombifolia			7	2	2														1					1
Dillwynia retorta	1	10	11	8	5	1		6			6	7	5	7	7	6	12	11	8	6	2	1	6	8
Eriostemon australasius						1	2						1					1	2				1	
Gompholobium virgatum										2									1					
Gonocarpus teucrioides			1					1		2	1						2						1	
Hibbertia obtusifolia							1					1												
Leucopogon ericoides			1	2			4							1					2		2	1	3	2
Leucopogon parviflorus																								
Leucopogon virgatus							1		1					1										
Monotoca scoparia							3				1			1	1	1	2							
Phyllota phylicoides						6	3	6	6					1				3						3
Pimelea linifolia																								
Platysace linearifolia								2		1	1	1			1			1					1	
Ricinocarpos pinifolius			1		3	1	2	1	3	3		2		1	2	4	1	4	2	1	4	1	1	
(v) Pteridophytes																								
Blechnum cartilagineum	1																							
Pteridium esculentum	10	6	8	4	4	9	8	5	7	4	4	8	7	3	8	8	4	3	5	1	1	6		1
(vi) Grasses & lilies																								
Dianella caerulea														1		1								
Imperata cylindrica																								
Panicum simile										1	1													
Themeda australis									4	2			4			5	3	1						

250	**260**	**270**	**280**	**290**	**300**	**310**	**320**	**330**	**340**	**350**	**360**	**370**	**380**	**390**	**400**	**410**	**420**	**430**	**440**	**450**	**460**	**470**	**480**	**490**	**500**	
6.4	**6.5**	**6.4**	**6.3**	**6.4**	**6.5**	**6.5**	**6.6**	**6.6**	**6.6**	**6.5**	**6.4**	**6.3**	**6.3**	**6.2**	**6.2**	**6.2**	**6.1**	**6**	**6**	**6**	**6**	**6.1**	**6.1**	**6.2**	**6.3**	
	>4		**>4**		**>4**		**1.5**		**2**		**>3**		**>4**		**>4**		**>4**		**>2**		**>4**		**>4**		**4**	
																										Total Number
																										13
											2	3	5	2	10	7	6	2	2	3	1	6				49
											2	3	5	1	5	7	6	2		2		2				35
1	5	2	4	2	1	4	3	3	5	1			2	2	2		1		1	1	1	6	15	12	10	260
1	1		2			2	3	3	4				2	2	2		1		1	1		1	4	2		55
1	1		1				3			1	1		1	2	2	1	1			1	1	1	1		2	38
1	1	1		1	2	1			1	1	1															21
																				1						1
								2																		2
																										Total cover score
																										234
	4	8	20	4	5	12	20	2	10	19	20	4		15	12	12	14	4	17		12	20	6		3	376
14	20	17	8		15	4																				188
																										15
																			7	20	10	2				39
											2	15	20	7	10	4	9	10		1			2			80
	6			11				8	5													1	2	1	4	82
																										1
												1			2			4	2	4	1	1	2			19
1	1	1				1			2		1					1			1		1					15
						2		1	3	2			1	1	1	4	1		2	2	2	2				57
		1	3						2					2			1				1	1			1	20
1	2		1	1	2	3	3	1																		27
6		1		2	1	1	4		2		1		3	1				1	4	3	5	2	1	1	2	175
1		1	4	2				3				1		2		1		1	2	1			1		1	29
2				1		1	1	2	1			1	2	1	2	1	1	1				2	1			23
2				1				1	1					1							1					15
			1					1											1		1					6
1						2				5		2	1								1	1			1	32
					1																					1
	1											2					1					1	1		1	10
				4		1	1	5				2	1		1	1	3	2	3	1		1	1	1		37
	2		1	7	1	2	1	2			2						1	5	2	6	6	4	1		2	73
														1	1				1							3
	1	2		1	4	1	1	2	1	1			2	5	5	1	2	1	4		1		1	1	1	46
	5	3	2			1	2	4	2		1	2	1	3	2	3		1	1	2	1	2				75
																										1
6	4		3	2	5	5	6	7	3	9	5	10	6	2	2	3	5	2	3	5	4	1	7	2	3	234
															1											3
								1							1											2
																										2
1	7			4	2	8	3	1	1		3	1	2	6	5	1	1			1	1		1			68

Table 6 (cont.)

Distance (m)	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**230**	**240**
Height of surface (m)	**0.9**	**2.4**	**7**	**10.9**	**12.6**	**12.6**	**12**	**11.9**	**10.5**	**9.1**	**7.7**	**7**	**6.6**	**6.5**	**6.4**	**6.5**	**6.5**	**6.5**	**6.6**	**6.6**	**6.7**	**6.6**	**6.6**	**6.5**
Depth to B horizon (m)	**1.3**	**1.9**	**1.2**	**2.2**	**3.3**	**2.4**	**3**	**2.5**	**2.6**	**>4**	**>4**	**>4**		**>4**		**>4**		**1**		**1.8**		**1.6**		**1.8**
(vii) Restiads, sedges & lomandra																								
Baloskion tetraphyllum	13	9																						
Hypolaena fastigiata													6	8	15	12	13	14	14	10	11	10	14	14
Leptocarpus tenax	5																							
Lomandra glauca					1			1	2	1				2				1		2				
Lomandra longifolia				2						2		2	6	1	1		1	2	2		1		2	
(viii) Subshrub & herbs																								
Pomax umbellata			1				1																	
(ix) Xanthorrhoea																								
Xanthorrhoea glauca		4		2	16	12		2	2		4						1			5	3		2	
Bare ground				**1**			**1**		**1**							**1**						**1**		

most westerly, Transect 3 (App. 4) commenced in a drainage channel 0–30 m in vegetation somewhat intermediate between Swamp and Wet Heath, crossed a deeper drainage channel with *Eucalyptus robusta* Swamp Forest at 200–240 m and ended at its lowest point at the edge of the river floodplain in Swamp with *Blechnum indicum*, *Chorizandra sphaerocephala* and *Phragmites australis*. The two ridges crossed by Long Transect 3 stand about 7 m above the river floodplain.

In the Bombah sand mass (Bsm), a similar difference occurs in height (6–6.5 m) between adjoining swampy ground and the relatively level central area crossed by Long Transect 5 (Table 6). At the southern, lakeside, end of the transect, from 0–120 m, there is a ridge rising to 12 m with a steep scarp slope facing the lake. This ridge is shown in Murphy's (1995) Soil Landscape map. On this ridge, *Angophora costata* and juvenile *Banksia serrata* were generally more common than in the rest of the transect. Depths to the B horizon varied along the transect without any particular pattern.

In Long Transect 6, which traversed DHF, IDF and DSF, depths to the B horizon appeared to be greatest beneath IDF, where height of the surface above the edge of Bombah Bog was greatest; Bombah Bog was reached at 330 m (Table 7).

Sand masses and their vegetation

The two most extensive types of sand mass, the Pleistocene inner Barrier strand plain (Pib) and the Bombah sand mass (Bsm) have DSF, IDF or DHF on freely draining sites, whereas the Boolambayte sand ridge (Bsr) has only has only DSF. DSF also occurs on some lake sand bars such as on the bar running west from Bombah Point and those just east of Nerong. Small sand bars between the Bombah sand mass and the shores of Bombah Broadwater carry open-scrub (*sensu* Specht 1970) of *Banksia integrifolia* and *Banksia serrata* and other species of shrubs.

On the Boolambayte sand ridge (Bsr), DSF varies in its understorey from north to south. In the south, it is more sclerophyllous with a higher density of *Banksia serrata* than in the north where the understorey is quite mesophyllous. About 700 m from its northern end, there is a small patch of pines and other spp. not endemic to the site, clearly an erstwhile garden. A tiny outcrop of rock is present. Augering the soil within 2 to 5 m from the outcrop encountered rock at 0.6 to 1.8 m deep.

Dry Heath Forest (DHF) occupies most of the freely draining sands of the Pleistocene inner Barrier strand plain (Pib) (Fig. 3). There is little variation apparent in DHF related to distance of the ridges from the sea; *Eucalyptus signata* is however the most common species of tree on the most inland ridge but not on other ridges. Dry Sclerophyll Forest (DSF) occurs on the plain in two situations. The first, where sand lies close to substrata other than beach sand, carries DSF usually with some species, such as *Allocasuarina* spp. that usually occur on rock-based soils (see Transects 10, 27, 31, 33, 42 & 43 (Fig. 2 & App. 1)). The second is where fluvial disturbance might have been expected to have occurred since the original marine deposition of the sand (see Transects 2, 44 & 45 (Fig. 2 & App. 1)). Intermediate Dry Forest (IDF) occurs on the plain close to DSF, again where fluvial disturbance might have been expected (see Transects 21 & 39 (Fig. 2 & App. 1)).

In contrast, on the Bombah sand mass (Bsm), Intermediate Dry Forest (IDF) is the most extensive vegetation (Fig. 3). Dry Sclerophyll Forest (DSF) occurs in bands along edges, most extensively where disturbance from the river, lake, wind or the brief Postglacial marine incursion (Martin 1986) would have been expected. Dry Heath Forest (DHF) is limited to an area near the eastern end of the sand mass.

Discussion

Vegetation & geomorphological processes

Geomorphological processes are summarised in Thom *et al.* (1992) for the two sand masses originally laid down about 125,000 years ago, the Pleistocene beach system (Pib) and the Bombah sand mass (Bsm).

250	**260**	**270**	**280**	**290**	**300**	**310**	**320**	**330**	**340**	**350**	**360**	**370**	**380**	**390**	**400**	**410**	**420**	**430**	**440**	**450**	**460**	**470**	**480**	**490**	**500**	
6.4	**6.5**	**6.4**	**6.3**	**6.4**	**6.5**	**6.5**	**6.6**	**6.6**	**6.6**	**6.5**	**6.4**	**6.3**	**6.3**	**6.2**	**6.2**	**6.2**	**6.1**	**6**	**6**	**6**	**6**	**6.1**	**6.1**	**6.2**	**6.3**	
	>4		**>4**		**>4**		**1.5**		**2**		**>3**		**>4**		**>4**		**>4**		**>2**		**>4**		**>4**		**4**	
																										22
10	6	5	7	3	6	4	7	5	10	6	7	6	8	6	7	5	9	10	1	4	9	10	6	8	16	322
																										5
		1	2	2	1		1	2					2	1						1	1		1			25
							1	1	1										2							27
													2													4
4		1	4	5		14	5	1	1	2			6	7	2	7	10	7			1		2	13	4	149
1																**1**		**1**								**8**

How Bombah Bog was formed in the Postglacial between Bsm and Pib is based on data of Martin (1986). Recognition of residual "islands" of Pib in north-eastern portion of Bombah Bog is from this study, with an explanation that the coffee rock of the indurated B horizon of their soils protected these small areas from destruction by wave action during the brief Postglacial Marine Transgression. Recognition of the Boolambayte sand ridge (Bsr) also derives from this study. It is suggested that it formed after the Postglacial Marine Transgression as waters drained from Boolambayte Lake into Bombah Broadwater over an approximately one-kilometre wide channel between Bombah Point and the eastern end of the Bombah sand mass (Bsm). It is suggested that as the Boolambayte sand ridge (Bsr) formed, it blocked Bombah Bog off from contact with Boolambayte Lake, and that Bombah Bog then began to drain into Bombah Broadwater through the present drainage channel between the western side of the southen end of Bsr and the eastern end of Bsm. It is suggested that, subsequently, the present lake sand bar formed growing westward from the western end of rocks at Bombah Point, eventually blocking off the channel there between Bombah Broadwater and Boolambayte Lake, leaving only the present narrow channel interconnecting the lakes east of Bombah Point.

Thom et al. (1992) and Murphy (1995) did not recognise the eastern drainage channel from Bombah Bog into Bombah Broadwater, and showed a continuous connection between sands of Boolambayte sand ridge (Bsr) and those of Bombah sand mass (Bsm), assigning their deposition to the Pleistocene.

Evidence from vegetation is consistent with the sequence of geomorphological processes postulated in this study. The recent origin suggested for the lake sand bar running west from Bombah Point is consistent with the presence in its vegetation of both *Banksia serrata* and *Banksia integrifolia*. *Banksia integrifolia* does not occur either in the area of this study are or in the Eurunderee area (Myerscough & Carolin 1986) except on fairly recently deposited sands. Its trees are confined to *Angophora costata*, though the development of the sand bar as a camping ground over the last 100 years (Broomham 2010) may have seen removal of other species of tree. Elsewhere more than one species of tree occur in Dry Sclerophyll Forest (DSF). Dry Sclerophyll Forest (DSF) is the sole vegetation of freely draining sands of Boolambayte sand ridge (Bsr), consistent with the origin of Bsr following the Postglacial Marine Transgression that, on Martin's (1986) evidence, initiated Bombah Bog (c. 8,000 years ago).

On the Pleistocene sands of Pib and Bsm, DSF only occurs in places where either the sands lie close to other substrata or where fluvial disturbance or recent wind or wave activity near lake shores might have been expected.

On Bsm, DSF, on the steep scarp face facing the lake and high ridge inland of this, gives way further inland to Intermediate Dry Forest (IDF) (Table 6). IDF is the most widespread vegetation of Bsm. In that regard, it is similar to the sand mass in the Eurunderee area that Thom *et al.* (1992) suggested was formed into its present shape in Glacial times by strong westerly winds; Myerscough and Carolin (1986) showed that much of the vegetation of freely draining areas of this sand mass was IDF. Thom *et al.* (1992) suggest that much of the surface of Bsm was similarly affected by westerly winds in Glacial times (c. 20,000 years ago). It is only in an area near the eastern end of Bsm that DHF occurs, which may be expected to have been relatively sheltered from westerly winds in Glacial times, and thus little disturbed.

DHF is the predominant vegetation of freely draining areas of the Pleistocene beach system (Pib). This is consistent with most of these areas having had little disturbance since they were laid down 125,000 years ago.

Vegetation & nutrient status

Nutrient status, in the sense of working capital of nutrients in circulation in the vegetation/soil system (Beadle & Burges 1949), was hypothesised by Myerscough and Carolin (1986) to be graded in the Eurunderee area from being highest in DSF, through IDF to lowest in DHF. There is nothing in this study that would refute this. Indeed, observations are consistent with it. Firstly, the generally taller, less open, tree canopy of DSF than DHF, together with a more grassy, less sclerophyllous, understorey indicate more biomass and higher quantities of

Table 7. Transect 6 (bearing 360 degrees).

Approximate vegetation boundary											**DHF**	**IDF**												**IDF**	**DSF**									
Distance (m)	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330
Height of surface (m)	4.5	4.4	4.2	3.9	3.6	3.4	3.4	3.5	3.5	3.5	3.5	3.7	4.1	4.3	4.2	4.1	4.2	4.5	4.9	5.6	6	6.4	6.1	5.6	5	4.4	3.7	3.6	3	2.3	1.6	0.9	0.4	0
Depth to B horizon (m)	>4		>4		1.1		0.9		1.6		1.8		2.4		2.7		3.1		4		4		4		4		3.9		3		2.1			
Depth to water table (m)	3.8		3.5		3		3		2.9		3.2		4		3.8		4										3.5		2.7		2		1.6	

nutrients per unit area than in DHF. Secondly, the small sample of soils examined (Table 3) indicates that the DSF soils are young podzols lacking the highly indurated B horizons of the highly developed podzols of those DHF sites in which B horizons were reached. It can be argued that the younger the podzol the more likely is it to contain reserves of nutrients. Furthermore, in some of the DHF sites the watertable was reached before the B horizon. It is probable that their podzols were formed soon after the Pleistocene beach ridges were deposited 125,000 years ago and that their B horizons became progressively deeper as sea levels fell. As sea levels rose on the onset of the Holocene, rising watertables would have been expected to have submerged their B horizons. Thus, three processes of nutrient depletion would have been expected over time in the Pleistocene beach ridge sands carrying DHF. The first would have been loss of nutrients in numerous bushfires; the second, leaching out of nutrients in podzol formation; and, the third, loss in soil volume available for roots to garner nutrients as the watertable rose. The first and second processes would be expected to be occurring in the DSF sites, but not to have occurred over a long duration as in DHF sites, and the third process not to have occurred at all.

Variation in vegetation

Vegetation varies in a continuous way across DSF, IDF and DHF based on their floristic composition (Fig. 4). The distributions and abundances of numerous, widely ranging spp. of understorey shrubs are probably largely responsible for the tight clustering of DSF, IDF and DHF under the technique of ordination used. Some of these species are obligate-seeders, only regenerating from seed after fires of all but the lowest intensities (see Myerscough *et al.* 1995 for fire behaviour of many of them in heaths of the Eurunderee area). The relative occurrence of *Banksia aemula* and *Banksia serrata* distinguished DSF (*Banksia serrata* alone), IDF (*Banksia serrata* and *Banksia aemula* together) and DHF (*Banksia aemula* alone). *Banksia aemula* appears to occur solely on old deposits of sand, at least in the southern parts of its range. South of Newcastle, these are aeolian Pleistocene sands deposited close to coastal cliffs, such as at Wyburn Head and La Perouse (Benson 1986), with the notable exception of its occurrence much further inland on old alluvial sands at Agnes Banks (Benson 1981). There is variation across DSF, IDF and DHF in their relative grassiness; DSF the most grassy, and DHF the least but with the greatest abundance of the restiad *Hypolaena fastigiata*. The banksias, grasses and *Hypolaena fastigiata* are all resprouting species, some of whose mature plants survive even the most intense fires and after fire sprout fresh leafy shoots. All the species of tree in DSF, IDF and DHF are resprouters. *Corymbia gummifera* occurs with almost uniform abundance across DSF, IDF and DHF. *Eucalyptus signata*, a less abundant species, is almost entirely confined to DHF, and does not occur at all in DSF.

Variation occurs within DSF, IDF and DHF. Floristic variation in DSF is apparent between sites close to substratum other than sand and sites solely on sand. In DHF, structural variation is apparent between sites where tree cover is low, woodland or open-woodland sites, and those where it is higher, open-forest sites. Possibly, this variation in DHF relates to relative nutrient status of sites.

Nomenclature of vegetation

The close floristic similarity of DSF, IDF and DHF justifies their inclusion in Keith's (2004) Coastal Dune Dry Sclerophyll Forests.

The original choice of the names Dry Sclerophyll Forest (DSF), Intermediate Dry Forest (IDF) and Dry Heath Forest (DHF) by Myerscough and Carolin (1986) is open to criticism. It is using Dry Sclerophyll Forest in a local restricted sense, while dry sclerophyll forest is defined by Beadle and Costin (1952) as a very broad category of vegetation. However, the names Dry Sclerophyll Forest (DSF), Intermediate Dry Forest (IDF) and Dry Heath Forest (DHF) were retained in this study to allow ready comparison to vegetation of the nearby Eurunderee area.

Vegetation similarities in other areas

The Eurunderee area and the Upper Myall River valley differ in the way DHF and DSF are distributed across their sand masses, and indeed in their sand masses. The Eurunderee area, as used here and in Myerscough and Carolin (1986), includes the Eurunderee Embayment of Thom *et al.* 1992 and the large triangular Holocene transgressive dunefield lying between the Big Gibber and Seal Rocks that runs inland to the shores of Myall Lake and reaches its most northerly extent close to the entrance to Smiths Lake. The vegetation of these Holocene dunes, some of which reach 100 m in altitude, is, except just behind the beach front, DSF. The DSF reaches up to 40 m, tall open-forest of Specht (1970), and as low as 2–4 m in sites exposed to onshore winds without much apparent floristic variation (Myerscough & Carolin 1986). The Upper Myall River valley lacks any Holocene sand of the Outer Barrier or transgressive dunefield. The only wholly Holocene sand masses in the Upper Myall River valley appear to be the rather small Boolambayte sand ridge (Bsr), which carries DSF, and the even smaller lake sand bars (Lb). In short, DSF is extensive and well developed in the Eurunderee area across extensive Holocene sands, but such sands are almost lacking in the Upper Myall River valley, and areas of DSF in it are mostly confined to sites where Pleistocene sands affected by wind or flows of water since their deposition or sand thinly overlies other substratum.

In contrast, in the Upper Myall River valley DHF is much more widespread and well developed than in the Eurunderee area. Its Pleistocene beach ridges are higher and more extensive than in the Eurunderee area (Thom *et al.* 1992). In the Eurunderee embayment, DHF occurs on higher freely drained sands of the more inland of its Pleistocene beach ridges, but is not extensive. Not present in the Upper Myall River valley, but occurring in the Eurunderee area are a few patches of aeolian Pleistocene dunes such as on the north-eastern slopes of the Big Gibber and areas near Smiths Lake-; parts of these carry DHF (Myerscough & Carolin 1986), but, again, these are limited in extent. DHF in the Upper Myall River valley has a significant population of *Eucalyptus signata*, while only a few isolated trees of this species occur on Pleistocene sands in the Eurunderee Embayment (Myerscough & Carolin 1986).

The Eurunderee area and the Upper Myall River valley are rather similar in the occurrence and distribution of IDF on their sands. In each, IDF occurs most extensively on sands that Thom *et al.* (1992) suggest were moved and redeposited by wind in the Postglacial; sands, respectively, in the Pg area of Myerscough & Carolin (1986) and Bombah sand mass (Bsm) of this study. Both areas are also similar in each enclosing a *Lepironia* swamp in a small lagoon with relatively deep water. IDF also occurs in both this study and the Eurunderee area between DSF and DHF where edges of Pleistocene sand deposits appear to have secondarily disturbed; for instance, near the entrance to Smiths Lake in the Eurunderee area (Myerscough & Carolin 1986).

The Eurunderee area of Myerscough and Carolin (1986) with its large Holocene field of transgressive high dunes covered by particularly well developed DSF is unique on the coast of New South Wales. The Pleistocene beach system of the Upper Myall River valley with its extensive areas of DHF is much more typical of other Wallum country that lies in coastal areas between the Hunter valley and south-eastern Queensland, as described by Coaldrake (1961), Griffith *et al.* (2003) and Griffith & Wilson (2007).

Wider context of the vegetation

The forest of the freely drained sands of the Upper Myall River valley and other Wallum country fall within Keith's (2011) subformation of Dry Sclerophyll Forests. They are closely related to vegetation on other high-quartz sediments as defined by Keith (2011). Nevertheless, the increased grassiness of the understorey from DHF to DSF in this study parallels a similar general trend in the Dry Sclerophyll Forest subformation of Keith (2011) from forests on high-quartz to those on more felsic sediments. This increased grassiness of the understorey from DHF to DSF probably also conforms to Grime's (1979) continuum of increasing competitive species and less stress-tolerant species with increasing levels of plant nutrients in the soil and vegetation.

The vegetation of the freely drained sands of the Upper Myall River valley conforms to the sort of vegetation expected under the "Nutrient-Poverty/Intense-Fire Theory" of Orians & Milweski (2007). It does not fit within Hopper's (2009) category of "Old Climatically Buffered Infertile Landscapes (OCBILs)", as the sands of the valley are not an "old" landscape in Hopper's sense as the earliest sands in the beach ridges were only laid down about 125,000 years ago (Thom *et al.* 1992). Their vegetation does not show the high degree of endemism expected in the OCBILs of Hopper (2009).

Vegetation type and population dynamics

Population dynamics of species may differ across types of vegetation. DSF and DHF would be expected to differ in rates at which individuals of resprouting species turn over. Turn-over of individuals might be expected to be slower in the less fertile DHF than in DSF. This could be tested within species that occur in both DSF and DHF, such as *Hypolaena fastigiata* and *Pteridium esculentum* (Table 2). In Britain, growth of rhizomes and production of fronds have been extensively studied over many years in *Pteridium aquilinum* (L.) Kuhn (see review of Marrs & Watt 2006). It would be instructive to compare patterns of rhizome growth and frond production between DSF and DHF, and perhaps, using DNA analyses, to look at the extent of individual clones of bracken in DSF and DHF. If estimates of rates of spread of individual clones could be made in each of DSF and DHF, their relative extents could then be used to estimate their ages and how often clones are established from sporelings in each. Similarly, using DNA analyses, the suggestion could also be tested of clonal spread from lateral growth and subsequent fragmentation of lignotubers in species such as *Corymbia gummifera* (Mullette 1978) and *Banksia aemula* (Siddiqi 1971, Myerscough & Carolin 1986). In *Banksia aemula*, establishment from seedlings appears to be a rare event in Dry Heath on Pleistocene beach ridges of the Eurunderee embayment (Myerscough 2009); it may also be rare in DHF, and some mature individuals may not only be long-lived but have originated by fragmentation of lignotubers over long periods. DNA analyses might also be used to test whether individual clones of *Hypolaena fastigiata* are widely spread along particular beach ridges, indicating that establishment of plants from seed is relatively rare in that species. If a particular clone were found in DHF on at least two ridges, now separated by periodically waterlogged habitat, it might indicate that that the clone had become established before the Holocene rise in sea level had raised water tables. In short, it is postulated that turn-over in individuals in long-lived resprouting species is longer in DHF than in DSF. Various aspects of this hypothesis can be tested by further observations, probably using DNA analyses to identify clones and their extents.

Conservation of vegetation of old beach ridges

Conservation of old beach ridges and their vegetation is an issue along the whole of the NSW coastline (Griffith & Wilson, 2007, Paine *et al*., 2010, Tozer *et al*. 2010). Their geomorphology, vegetation and soils have intrinsic scientific interest, and, as outlined above, are a fertile field for research. Their vegetation is an element in the whole mosaic of native vegetation that is sought to be conserved across the landscape (eg. Tozer *et al*. 2010, Keith 2011).

In common with other systems of old beach sand ridges, that of the Upper Myall River valley faces change from rise of sea level and from development. The vegetation mapped in Fig. 3 is now out of date because significant areas of native vegetation have been altered by developments on the most inland of the sand ridges north of the boundary of the national park. Rise of sea level could raise water tables further restricting areas of freely draining sands and their vegetation. Should the Outer Barrier dunes be breached, for instance, near Mungo Brush, a marine transgression might recur, similar to the one in the Postglacial described by Martin (1986) that initiated Bombah Bog.

Conclusion

In the Upper Myall River valley, Dry Heath Forest (DHF), Intermediate Dry Forest (IDF) and Dry Sclerophyll Forest (DSF) occur on freely drained beach sands. DHF is the most widespread, occurring on Pleistocene sands of beach ridges that appear to have little disturbed since they were deposited c. 125,000 years ago. DSF occurs on the edges of Pleistocene beach sand ridges where they have either been disturbed by wind or water since their deposition or where they shallowly overlie other substrata. DSF also occurs on small areas of Holocene sand deposited in the valley; namely, well developed sand bars on part of the shores of Bombah Broadwater, and the Boolambayte sand ridge (Bsr), that is postulated to have formed on the western side of the southern end of Boolambayte Lake, isolating Bombah Bog from Boolambayte Lake. IDF most extensively occurs on the Bombah sand mass (Bsm), a Pleistocene sand mass that Thom *et al.* (1992) suggest was reworked by strong westerly winds in the Postglacial. Small areas of IDF also occur between DSF and DHF on edges of some ridges of the Pleistocene beach system (Inner Barrier strand plain of Thom *et al.* (1992)), where sands of the ridges would have been affected by river water. In short, variation in vegetation on sand ridges in the Upper Myall River valley can be related to geomorphological processes and when the processes occurred.

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Appendix 1: Species and their scored presence (max. 10) in each of 48 transects (50 x 5 m)

Transect	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Map ref. Easting	307	296	301	313	310	304	307	318	318	325	305	297	282	280	279	283	293	283	286	284	281	287
Map ref. Northing	49	41	38	47	42	31	35	36	18	39	17	15	58	61	63	65	71	71	61	58	48	56
Vegetation	DHF	DSF	DHF	WH	DHF	DHF	DHF	DHF	DSF	DSF	DSF	IDF	DHF	DHF	WHF	DHF	Sw	WHF	WH	WH	IDF	DHF
Acacia baueri															1							
Acacia elongata																				2		
Acacia longifolia										2												
Acacia quadrilateralis					9																	
Acacia suaveolens	3	1	2			3	2	7	1		4	8		2							1	7
Acacia terminalis																		4				
Acacia ulicifolia	5	2	10			1	5	10	8	4	2	9		2		1		3			4	2
Actinotus helianthi	4													5		2						4
Allocasuarina littoralis																						
Allocasuarina torulosa																						
Amperea xiphoclada	3				1		2	1	3						1	3		2				
Angophora costata	5								4	4	1		5	6	1	3		6			5	
Anisopogon avenaceus																						
Aotus ericoides													1		5				1			
Astroloma pinifolius								1													2	
Axonopus affinis																						
Baeckea imbricata					4																	
Baloskion pallens	6			2	3								3				10		6			
Baloskion tetraphyllum	8						6						8	5		8				8		
Banksia aemula	10		10		10	10	10	10				10	10	10		10					3	10
Banksia oblongifolia	1			4											9	1			8	4		
Banksia robur																				4		
Banksia serrata		9							9	8	8	2									7	
Banksia spinulosa var. *collina*																						
Baumea acuta				7																		
Baumea arthrophylla				4													6					
Baumea juncea																						
Baumea rubinosa																						
Baumea teretifolia																			1	3		
Billardiera scandens																						
Blandfordia grandiflora															5				2			
Blechnum cartilagineum																	3					
Blechnum indicum																						
Boronia falcifolia																				8		
Boronia parviflora																				2		
Boronia pinnata	4				7		1	1		1			6	1	1	3		3		2		
Boronia sp.																						
Bossiaea ensata			1			7	5		2		3	1										6
Bossiaea heterophylla	8	10	10		5	10	7	8	6	6		9	9	7		2					9	9
Bossiaea rhombifolia		9				2			3	9	9	2										
Brachylomadaphnoides		5	2			5		1	8		5	8				1					6	5
Caesia parviflora var. *vittata*																			1			
Callistemon citrinus				9													6		6	9		
Calochlaena dubia																						
Calytrix tetragona						5										5						2
Casuarina glauca																						
Caustis pentandra																						6
Chorizandra sphaerocephala				5													2		2	4		
Coleocarya gracilis			2																			
Conospermum taxifolium		1	4			2			1	2	1	1									2	3
Conyza bonariensis																					1	
Convolvulus erubescens																						
Corymbia gummifera	2	4	4		6	3	9	10	8	3	5	5	5	3		4		10			4	6
Cotula coronopifolia																						
Cymbopogon refractus										1												
Dampiera stricta																4						
Dampiera sylvestris																						
Daviesia ulicifolia																		3				
Digitaria parviflora																						

23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
256	253	262	270	263	263	262	286	285	289	287	315	312	302	295	295	296	301	268	272	275	274	277	316	314	329
96	96	95	70	56	82	65	83	77	79	77	48	45	59	54	51	45	51	48	46	38	64	62	29	26	25
WH	?WH	WH	DHF	DSF	DHF	DHF	?WHF	DSF	WHF	DSF	DSF	DHF	DHF	DHF	DHF	IDF	DHF	WH	DSF	DSF	DSF	DSF	DSF	IDF	IDF
1																		3							
																					8		1		
												1	1											1	
			1	8		1		3	1		2				2	3	1		4	8		2	9	6	2
									2											1					
			7	2	1			6	9	10	2	4			1	3	3		3	1	4	6	3	6	6
			6											6	8		8								
				1					4	2										2					
								4																	
					1	7							3	1	1		1								
				3	1	2		7	9	7	7		2	2	3		1	1	10	5	6	4	8		
																				1					
						4					2		1												1
																	1			1					
							9	4	2																
													7												
8	1					8						1	9												
					3	1					5	1	9				4	3		2					
			10		10	10			3			10	10	10	10	8	10							1	8
		7							10				2												
		4																6							
				8				10		9	10								9	10	9	9	8	10	6
							1																		
		4					10																		
1																									
							1																		
5																		1							
2	9																	1							
								2													2				
		2																1							
3																		1							
																		1							
						4			1		1	6	1							1				6	
							3																		
			4	3							3			1	2	5				1			5	5	
			8	10	1	6				3	8	6	1	9	9	10	6		5	5	4	4	7	7	10
				2												4			7	8		9	5	1	
			7	1	2							1	1	5	8	8	2						1	6	
10	10	7					9											8							
										3											8				
					5				1					4	9		3								
							3																		
7	1	9																8							
									6					2	2	5	2							1	
				2										5	4				1	1				3	
							3																		
			6	6	2			5	5	4	3	9	2	2	2	7	2		4	6	5	4	4	9	9
							1																		
																				1					
						4							2												
											5	1								2					
								1	1												1				

Transect	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Map ref. Easting	307	296	301	313	310	304	307	318	318	325	305	297	282	280	279	283	293	283	286	284	281	287
Map ref. Northing	49	41	38	47	42	31	35	36	18	39	17	15	58	61	63	65	71	71	61	58	48	56
Vegetation	DHF	DSF	DHF	WH	DHF	DHF	DHF	DHF	DSF	DSF	DSF	IDF	DHF	DHF	WHF	DHF	Sw	WHF	WH	WH	IDF	DHF
Dianella caerulea		4	1				1		5	4	4			1				1			2	1
Dillwynia floribunda																			1	9		
Dillwynia glaberrima	7	1	1		6	6	1						6	2		7					1	
Dillwynia retorta			1				1	9	4	5	3	8		5				7			6	2
Dodonaea triquetra																						
Doryanthes excelsa																						
Drosera auriculata																						
Drosera peltata	6				10																	
Drosera spathulata																						
Echinopogon ovatus																		4				
Empodisma minus				1											9					3		
Entolasia marginata																						
Entolasia stricta				5														8	1	3		
Epacris microphylla																				2		
Epacris obtusifolia																				7		
Epacris pulchella	1							1		1		2		4		1		4				
Eragrostis brownii										1												
Eragrostis parviflora																					2	
Eriostemon australasius	4	1	8		5	9	6	7	6	1	9	8	2	7		1					5	10
Eriocaulon scariosa																						
Eucalyptus amplifolia																						
Eucalyptus pilularis		5	3			5			3	2	2	4		3							7	3
Eucalyptus resinifera																		5				
Eucalyptus robusta																	4			1		
Eucalyptus signata	1				3		3	4					9		10	4						
Eurychorda complanata																				6		
Euryomyrtus ramosissima	1																					
Exocarpos cupressiformis																						
Exocarpos strictus								1		4												
Gahnia clarkei																						
Gahnia sieberiana																				1		
Gleichenia dicarpa																						
Glochidion ferdinandi																						
Glycine clandestina																						
Glycine tabacina		1									1										1	
Gompholobium latifolium	2	2					5	4	1	3	7											
Gompholobium pinnatum																		6				
Gompholobium virgatum var. *virgatum*			1			4	1	1	10			8		1		4					2	2
Gonocarpus micrantha																		1	2	1		
Gonocarpus teucrioides	2	6	8			5	5	2	7	1	6	3				2		2			9	5
Goodenia heterophylla		1																6				
Goodenia paniculata				3																		
Goodenia stelligera																			1			
Gratiola pedunculata																						
Haemodorum planifolium			1	4		3	2				2		2		1	7			1		1	4
Hakea teretifolia																						
Hardenbergia violacea		1						4	4	3	2							2				
Hemarthria uncinata																	1					
Hibbertia aspera																						
Hibbertia fasciculata	8				5		4						9	6	2	5						
Hibbertia linearis	6		1		2		4					1		1								1
Hibbertia obtusifolia		8	9			8	3	9	8	5	9	5	4	4							7	5
Hibbertia salicifolia																				5		
Hibbertia scandens																						
Hovea linearis																						
Hydrocotyle tripartita																						
Hypericum japonicum																		1				
Hypolaena fastigiata	8		7		10	9	10	10		8	7	10	9	7		9						10

23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
256	253	262	270	263	263	262	286	285	289	287	315	312	302	295	295	296	301	268	272	275	274	277	316	314	329
96	96	95	70	56	82	65	83	77	79	77	48	45	59	54	51	45	51	48	46	38	64	62	29	26	25
WH	?WH	WH	DHF	DSF	DHF	DHF	?WHF	DSF	WHF	DSF	DSF	DHF	DHF	DHF	DHF	IDF	DHF	WH	DSF	DSF	DSF	DSF	DSF	IDF	IDF
	1		1	1			1	2		3	8								8	3	6	5	6	3	1
				2	4	8							8	5	1		1								
			2		7				8	4		5		3	2	8	4			1			9	9	4
																					9				
																				2					
												1													
												1	6												
1		1																3							
								1		1										1					
		3																1							
5	8																	2							
	10	7					3		1									5							
																		1							
									4			1	1							1				2	
									1										2	4					
								1	1																
			10		4	5						5	1	9	8	8	6						9	9	8
3																									
							2																		
			4	2				4			2			3		6			5	4	4	7	3		2
							7		1																
										1								7							
					1	6						7	2	2			8							2	
		3																4							
																							1		
							4		1	2								1							
		3																							
																		1							
								2												1	2	1			
				4															1	1	2	4			
								1		5															
								3	4	5	10								3	4	4				3
									4																
			2		4									2	1				2				7	4	5
2	2	1					1		2									8							
				9				6	4	4	8				1	6			3	2	2	3	4	3	1
6	3						4																		
																		5							
2																									
						6			1					5	5		3	1		3			1		
		5																5							
				3						1						2				1	2		8	1	2
9	4						3											1							
																				1					
				1	6							2	3	5	3		5			1					
												9			4		3			8		2			
			9	10	5	1		7	1	9	4			4	4	8	5		4	3	9	8	9	8	10
								1		1															
				2				1														1	1		
							2																		
							5																		
			1		10	10			4			10	10	10	10	5	10		1	10			6	10	10

Transect	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Map ref. Easting	307	296	301	313	310	304	307	318	318	325	305	297	282	280	279	283	293	283	286	284	281	287
Map ref. Northing	49	41	38	47	42	31	35	36	18	39	17	15	58	61	63	65	71	71	61	58	48	56
Vegetation	DHF	DSF	DHF	WH	DHF	DHF	DHF	DHF	DSF	DSF	DSF	IDF	DHF	DHF	WHF	DHF	Sw	WHF	WH	WH	IDF	DHF
Imperata cylindrica										6								4			2	
Indigofera australis																					2	
Ischaemum australe																						
Isopogon anemonifolius																						
Kennedia prostrata		3																1				
Kennedia rubicunda																						
Kunzea capitata																				1		
Laxmannia gracilis																						
Lepidosperma elatius																						
Lepidosperma filiforme																	9					
Lepidosperma laterale																						
Leptocarpus tenax	3			10									2	1	7	6			10	4		
Leptomeria acida																						
Leptospermum juniperinium				3											1		1			10		
Leptospermum liversidgei																	1		3	10		
Leptospermum polygalifolium	9			1	8		3	1					10	5	10	8		7	5	1		
Leptospermum trinervium	6	3	8		5		6	1	3		2	8		8							4	7
Lepyrodia muelleri				2																		
Lepyrodia scariosa															3			5				
Leucopogon ericoides							1	8	8	2	2	7		4		1					7	1
Leucopogon lanceolatus											4											
Leucopogon parviflorus	5	1	1		7		2					3	8	4		1					3	
Leucopogon virgatus		3	7			6	3	2	5	1	7	5		2							7	3
Lobelia anceps																						
Lomandra glauca	2	3	6			6	2	2	10	5	7	4	3	6	5	4		2			6	3
Lomandra longifolia		9	5			3	2	10	8	8	8	2	6	5				8			10	
Lomatia silaifolia																						
Macrozamia communis		7																				
Melaleuca decora																						
Melaleuca ericifolia																						
Melaleuca nodosa	4				4		2									9		7	4			
Melaleuca qinquenervia																						
Melaleuca sieberi				9											9			4	7			
Melaleuca thymifolia				10											1			1	9	3		
Melichrus procumbens																					1	
Micrantheum ericoides		6	1			4		1	6	2	3										3	3
Microlaena stipoides																		4				
Mirbelia rubiifolia																		3				
Monotoca elliptica								1	1	8												
Monotoca scoparia	3	1	2		4	7	4					2	4	6							2	7
Olax stricta						2			1			1										2
Opercularia aspera																						
Oxalis corniculata																						
Panicum simile	1	6	8	1		5	2	2	2	2	6	5		7	3			10	1		9	6
Paspalidium aversum																						
Paspalidium constrictum																						
Paspalum orbiculare																						
Patersonia glabrata											8											
Patersonia sericea																						
Persoonia lanceolata	1			2			1													4	1	
Persoonia levis			1				2		1	1	3				1	2		2				
Persoonia linearis																						
Philydrum lanuginosum																	1					
Phyllota phylicoides					2			7		3	3	6	1	2		5						1
Phragmites australis																						
Pimelea linifolia	8				1	1	2	1	3		2	1	5	3		4		2			10	1
Platylobium formosum																						
Platysace lanceolata																						
Platysace linearifolia	6	10	9		7	7	5	10	9		1	6	7	1		6						5

23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
256	253	262	270	263	263	262	286	285	289	287	315	312	302	295	295	296	301	268	272	275	274	277	316	314	329
96	96	95	70	56	82	65	83	77	79	77	48	45	59	54	51	45	51	48	46	38	64	62	29	26	25
WH	?WH	WH	DHF	DSF	DHF	DHF	?WHF	DSF	WHF	DSF	DSF	DHF	DHF	DHF	DHF	IDF	DHF	WH	DSF	DSF	DSF	DSF	DSF	IDF	IDF
				7				7		10	9								10	4	8	8			
											4										1				
							2																		
															1										
										1											7	1			
																				1					
																		2							
																				1					
		4																							
				1																					
1	1	3				3			9			5	1		1			6							
																							2	3	
		5					4											7							
		1																3							
			2		4	10	2		10		1	4	8				1	4		3				1	
			10		5	7						8	2	4	6	9	2		1	1				7	7
5	5	3					2																		
		5							2																
			1		2												2			1			4	10	4
				2				3			4								1	6	7	9			1
			6	1	4	6						8	8		1	2		1	2	1					
			7	2	7					1				3	10	6				2			4	3	3
							2																		
			6	1	9	6		2		2	3	1	9		4	1	1		8	2	2	8	6		4
			10	7	6	10		7	10	4	8				1	5			9	8	7	7	9		9
																				2					
				1										1											
							7																		
2	1																								
		2				2			10			1													
										1															
		10					10		4									9							
5	10	9					5											8							
								1		2															
											1			2		3				4				3	2
										1															
																		1							
				4				1												2	3	2		2	1
			7	2	8	2			1	1	1	6	6	8	5	2	4						1		
							1																		
							2																		
			4	7		1	4	7	8	7	3			2	3		1	2	6	7	9	9			
							5																		
							1																		
							6																		
								1								1		1							
			1	1																			3	1	
									1																
		1		1				6		2	2			4	1	1	1		2	4	1	3	1		
					1			3														1			
												2		6	1	1	6						6	9	6
5	3																								
		1			8				5					7	4		10		1				3	5	
				3				10		6											10	5			
					5																				
						6					10	8	2	7	8	9	1		4	3			8	4	3

Transect	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Map ref. Easting	307	296	301	313	310	304	307	318	318	325	305	297	282	280	279	283	293	283	286	284	281	287
Map ref. Northing	49	41	38	47	42	31	35	36	18	39	17	15	58	61	63	65	71	71	61	58	48	56
Vegetation	DHF	DSF	DHF	WH	DHF	DHF	DHF	DHF	DSF	DSF	DSF	IDF	DHF	DHF	WHF	DHF	Sw	WHF	WH	WH	IDF	DHF
Polyscias sambucifolia																						
Pomax umbellata		9	5			2	2		7	7	1	1		4				3			10	
Poranthera corymbosa									2													
Poranthera microphylla																					2	
Pratia pedunculata																						
Pseudanthus orientalis	1								1		1					3		1				
Pteridium esculentum	5	10	9			9	10	10	10	10	10	10	9	10							10	8
Ptilothrix deusta				4											8			8				
Pultenaea paleacea																						
Pultenaea villosa																						
Ricinocarpos pinifolius	9	8	8		10	9	2	5	9	2	10	7	2	1		5					10	10
Schizaea bifida					1			2			1											
Schoenus brevifolius				10											8				10	6		
Schoenus ericetorum			2			2	1															2
Schoenus maschalinus																						
Selaginella uliginosa	2			5	7								1	4	4			2		2		
Senecio aff. *lautus*		1									1											
Smilax glyciphylla																						
Sporadanthus interruptus	1			6	6		1						1	2		2		3		10		
Sprengelia incarnata				1																5		
Stackhousia viminea																			1			
Stylidium debile	1				2										6				5			
Stylidium graminifolium																		2				
Tetratheca ericifolia																1						
Tetratheca thymifolia	2				4				2	4	8	4										
Thelionema caespitosum																3						1
Themeda australis		8	7			10	1	7	8	9	9	7									7	3
Thysanotus juncifolius																						
Trachymene incisa			7			7	4		1			1	8	7				10			7	
Tricoryne simplex			2						2	2	5										8	
Villarsia exaltata				1													7		1			
Viminaria juncea				4																		
Viola hederacea																						
Wahlenbergia communis																						
Woollsia pungens																						
Xanthorrhoea fulva				10															10	1		
Xanthorrhoea glauca	3	1	1		4		1	2	8	2	4	7			10	1						1
Xanthorrhoea mac8ronema																						
Xanthosia pilosa										3				2							3	
Xyris gracilis														1	1							
Xyris juncea	1			1	1																	
Zieria laevigata	4		2		2		2					1	5	7		3		3				

23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
256	253	262	270	263	263	262	286	285	289	287	315	312	302	295	295	296	301	268	272	275	274	277	316	314	329
96	96	95	70	56	82	65	83	77	79	77	48	45	59	54	51	45	51	48	46	38	64	62	29	26	25
WH	?WH	WH	DHF	DSF	DHF	DHF	?WHF	DSF	WHF	DSF	DSF	DHF	DHF	DHF	DHF	IDF	DHF	WH	DSF	DSF	DSF	DSF	DSF	IDF	IDF
								2		3															
				2				7		1	8				1				5	5	8	9		1	5
														4											
				3															4		5	3			1
							6				1														
		1			5								2	1			1								
			10	10		4		10	3	10	10			10	6	10	8	4	10	10	10	10	10	9	10
							3																		
		10					1																		
	9						1																		
			10	2	8	7					5	10	8	10	9	9	8		1		8	4	9	7	
		1				1																	3		
10	10	10					8											8							
														1	7		2								
							2																		
2	1	7				5			2				5					6		1					
							1																		
		5				4						4	5					4							
																		1							
		1																							
	1												7												
						5																			
			3										1												
						3		2		1	7	3							5	1		1			4
				9			3	9	7	5	1				1	10		1	9	9	2	6	8	4	6
		1						1																	
								7	5	7	6						1		1	1	3	1	1	2	1
				6				4		3									4	3		3	1		
4																		2							
6																		1							
							8																		
											1														
												1													1
	1	1					1											1							
								2		2		7		1	2	2	3	1		8		3	3	7	1
				3				1		1	1										5	1			
			2																						
			6		3	7						2		4	4		4								

Appendix 2: Transect 1 (bearing 340 degrees): species cover over 10 m lengths (Max. score 20): spp. shown listed in Table 2 + *Leptospermum liversidgei* and *Baloskion tetraphyllum*

Distance (m)	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**
Height of surface (m)	**1.3**	**1.3**	**1.2**	**1.2**	**1.0**	**1.0**	**1.3**	**1.4**	**1.3**	**1.3**	**1.3**	**1.2**	**1.1**	**1.1**	**1.0**	**0.9**	**0.8**	**0.7**	**0.7**	**0.5**
Water table depth (m)				**0.9**	**0.7**	**0.8**	**0.7**	**0.9**	**1**	**1**	**1**	**0.9**	**1**	**1**	**1**	**1**	**1**	**1**	**1.1**	**1**
Tallest tree height (m)	**12**	**1.5**	**3**			**5**		**5**	**10**	**10**	**15**	**3**		**3**	**12**	**12**	**15**	**5**	**2**	**4**
(i) Tree species																				
Angophora costata	7															6	5			
Corymbia gummifera									1	3							8		11	3
Eucalyptus robusta																				
Eucalyptus signata	4							1			6				14	1	1	7		
(ii) Banksia species																				
Banksia aemula		3	3					4	2	3	1	6		5		3	4	10	1	7
Banksia oblongifolia	1	6	7	6																
(iii) Myrtaceous shrub spp.																				
Callistemon citrinus					4	1														
Leptospermum juniperinum																				
Leptospermum liversidgei				5	12	2	15	4												
Leptospermum polygalifolium	5	8	10	4				4	6	3	2	6	4							4
Leptospermum trinervium															1	13	1	6	1	3
Melaleuca nodosa								3		2	7	10	8	4	2	2				
Melaleuca sieberi				5	2	8	6													
Melaleuca thymifolia				3	14	4	2													
(iv) Shrub species																				
Acacia suaveolens																		1		
Acacia ulicifolia			1													1	1		1	
Bossiaea heterophylla									1							4	6	5	2	1
Dillwynia glaberrima	1	1	1						1	1					7					
Dillwynia retorta															1		1	1		
Eriostemon australasius																1				
Gonocarpus teucrioides			1												2		1			
Hibbertia fasciculata		2	1	1				1	5	1					1			3		
Leucopogon parviflorus									2											1
Monotoca scoparia										1						2		1		1
Pimelea linifolia			1					2		1	3	5	1	2	1	1	1		1	
Platysace linearifolia	8	1	2	1				4	4	2	1			1		7	3		2	5
Ricinocarpos pinifolius		1						1	2	1					3	2	1		4	1
Zieria laevigata		1							4			1				2	1		2	
(v) Pteridophytes																				
Selaginella uliginosa			2					3	5											
(vi) Grasses & lilies																				
Entolasia stricta			1	4	10	1	1													
Panicum simile	2	2					1			1										
(vii) Restiads, sedges & lomandra																				
Baloskion pallens	4	8	2	2	19	20	3	8	10	2										2
Baloskion tetraphyllum	1	2	9												9	16	16	18	16	9
Baumea arthrophylla				3		3	2													
Chorizandra sphaerocephala					10	1	8													
Hypolaena fastigiata	14	15	2						14	19	18	19	20	19	16	7	13	1	6	13
Leptocarpus tenax		1	2	2	10	9	8	5	1											
Lomandra glauca	1	2						1		1										1
Schoenus brevifolius					1	9	7													
Sporadanthus interruptus	5	3	4	13	2		7	7	1											
(viii) Subshrub & herbs																				
Trachymene incisa	2	2	3							1	1						1			
Villarsia exaltata					11	15	1													
(ix) Xanthorrhoea																				
Xanthorrhoea fulva				11	1		6	7												
Xanthorrhoea glauca	1	6	12	1				1			2				4	2		4	6	4
Bare ground	**1**	**1**	**1**											**1**	**1**					

210	**220**	**230**	**240**	**250**	**260**	**270**	**280**	**290**	**300**	**310**	**320**	**330**	**340**	**350**	**360**	**370**	**380**	**390**	**400**	
0.5	**0.5**	**0.4**	**0.2**	**0.0**	**0.2**	**0.1**	**0.2**	**0**	**0.2**	**0.3**	**0.3**	**0.3**	**0.4**	**0.5**	**0.5**	**0.6**	**0.5**	**0.6**	**0.5**	
0.9	**0.9**	**0.9**	**0.7**	**0.5**	**0.6**	**0.6**	**0.7**	**0.6**	**0.7**	**0.8**	**0.8**	**1**	**1.2**	**1**	**1.2**	**1.1**	**1.1**	**1**	**1.1**	
4	**4**	**10**	**10**	**5**					**1.5**	**5**			**5**	**5**	**6**	**10**	**10**	**4**	**10**	
																				Total cover score
																				Total
	2	1														4				25
																11	9			46
			1	5						2										8
		14	6										5	3	6	2	10		10	90
7	1	5	2										1	9	6			9	5	97
									2	13	7	1	1							44
					3	3			1											12
						1	5	2	12	5										25
			5	3			1			4	5	2	2							60
6	10	13									2	9	13	7	8	5	4	9	9	151
9															1	1				36
														1	3	2	2	6	4	56
				7	4	5	3	1	3	9	2	2								57
			2	5	12	12	8	15	6		2									85
																				1
															1	2				7
																	2	1		22
1															2	1	4		1	21
																				3
																				1
																				4
2	3												1					1	1	23
1														1	2	2				9
																			1	6
																				19
6	1																1			49
	1	1													1	1		4	2	26
	2																			13
						4	2	1				4	1	2						24
			4	11	6			1	6	2	5									52
																				6
14	15	9	12	3							5	6			1		4	3	1	153
	1	11												3	13	10	5	11	9	159
				11	15	12	8	11	9											74
			2	12	6	4	1	8	2	1										55
12	4	6												7	9	2	5	9	8	258
	9		5	1	10	10	11	3	3		7	6	6	1	3	3	7			123
1																	2	1	1	11
			3	13	19	18	12	16	16	9	4	3								130
7	4	3							1		1	12	8	3	4		1		3	89
																				10
			2	9					2											40
		17	15	2		5	5	5		7	5	5	15	15						121
															2					45
																				5

Appendix 3: Transect 2 (bearing 330 degrees): species cover over 10 m lengths (max. score 20): spp. shown listed in Table 2 + 7 other spp. (*Banksia robur*, *Leptospermum liversidgei*, *Blechnum indicum*, *Gleichenia dicarpa*, *Baloskion tetraphyllum*, *Baumea rubinosa* & *Empodisma minus*)

Distance (m)	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**
Height of surface (m)	**1.8**	**1.8**	**1.6**	**1.1**	**0.4**	**0.5**	**0.5**	**1.2**	**1.5**	**1.6**	**1.6**	**1.5**	**1.4**	**1.4**	**1.4**	**1.3**	**1.3**	**1.4**	**1.5**	**1.6**
Water table depth (m)				**1**	**0.2**	**0.2**	**0.6**	**1**	**1.2**	**1.3**	**1.2**	**1.2**	**1.2**	**1**	**1**	**1.2**	**1.2**	**1.2**	**1.3**	**1.3**
Tallest tree height (m)	**15**		**12**	**6**	**4**	**3**	**10**	**10**	**20**	**20**	**20**	**15**	**15**	**10**	**6**	**6**		**5**	**8**	**7**
(i) Tree species																				
Angophora costata								2											10	
Corymbia gummifera	4				1							5								
Eucalyptus robusta						6	3	3												
Eucalyptus signata			5						2	19	4	2	18	17						
(ii) Banksia species																				
Banksia aemula	9	2		2	7			2	9		2	2	1		5	5		3	5	10
Banksia robur																				
(iii) Myrtaceous shrub spp.																				
Callistemon citrinus																				
Leptospermum juniperinum					4	11	17	5												
Leptospermum liversidgei					4	11	4	2												
Leptospermum polygalifolium								5	2	2							2			
Leptospermum trinervium	3		5	3						1									4	6
(iv) Shrub species																				
Acacia ulicifolia				2												1		1		2
Bossiaea heterophylla	1	2	2					1	2										1	
Brachyloma daphnoides																				
Dillwynia glaberrima									3	4	1			2	1	1	1			
Dillwynia retorta			1	1					2	1	1									2
Eriostemon australasius	1	5	1	2															1	
Gompholobium virgatum		1																		
Gonocarpus teucrioides																				
Hibbertia fasciculata											1			1			1			
Hibbertia obtusifolia	4	2		1																
Leucopogon ericoides											1								1	2
Leucopogon parviflorus			1																	
Leucopogon virgatus	1									1		1								
Monotoca scoparia		3	2	1	2							2								2
Phyllota phylicoides																				
Pimelea linifolia													4	1		1	1		1	
Platysace linearifolia	2	4	2	1												2				
Ricinocarpos pinifolius	2	2	6						1		1								1	1
Zieria laevigata			1								1		3	1			1	3	3	
(v) Pteridophytes																				
Blechnum indicum					2	11	12	1												
Gleichenia dicarpa					1	9	13	1												
Pteridium esculentum	1		3								1								1	
Selaginella uliginosa								2												
(vi) Grasses & lilies																				
Entolasia stricta						1	1	3												
Panicum simile													1	1				1		
Themeda australis													2							
(vii) Restiads, sedges & lomandra																				
Baloskion pallens															3	3	1			
Baloskion tetraphyllum						12	17	8	6											
Baumea arthrophylla					1	2														
Baumea rubinosa																				
Chorizandra sphaerocephala					1															
Empodisma minus					1	15	12	1												
Hypolaena fastigiata			4	6					11	17	9	8	3	11	16	11	11	13	15	12
Leptocarpus tenax																				
Lomandra glauca														2	3	1		1		
Lomandra longifolia											1									
Schoenus brevifolius																				
Sporadanthus interruptus					11	5	3	9												
(viii) Subshrub & herbs																				
Pomax umbellata												1	2	3						
Trachymene incisa															1	1				
Villarsia exaltata								1												
(ix) Xanthorrhoea																				
Xanthorrhoea fulva						3	1	3												
Xanthorrhoea glauca								2												
Bare ground	**3**	**7**	**2**	**8**							**4**	**5**	**1**	**1**	**2**	**1**	**5**	**1**	**1**	**1**

210	**220**	**230**	**240**	**250**	**260**	**270**	**280**	**290**	**300**	**310**	**320**	**330**	**340**	**350**	**360**	**370**	**380**	**390**	**400**	
1.6	**1.6**	**1.5**	**1.5**	**1.3**	**1.2**	**1**	**0.9**	**0.4**	**0**	**0**	**0.7**	**0.7**	**0.5**	**0.8**	**1.1**	**1.4**	**1.4**	**1.5**	**1.5**	
1.4	**1.3**	**1.3**	**1.2**	**1**	**0.9**	**0.7**	**0.7**	**0.7**	**0.1**	**0.1**	**0.9**	**0.7**	**0.8**	**1.7**	**1.3**	**1.1**	**1.2**	**1.2**	**1.3**	
10	**6**	**6**	**20**	**20**	**20**	**20**	**15**		**8**	**8**	**8**	**14**	**14**	**6**	**8**	**18**	**18**	**6**	**4**	
																				Total
			2	10	15	1						7	1			7				55
																				10
							6		9	10	2			4						43
			10	10			2					6	12		12	4	11			134
10	6	3	3	1	3		4								1	7	3	3	2	110
									2	5	5									12
									5	9	7		4	13						38
								1	2	8	7			5						60
								12	3		10		7	8	1					62
					5	16	9	8	3			6	9	6	12	4	1			90
		6																1		29
2																				8
4																			2	15
1	3																	2	2	8
				1	1													4		19
			3	1												1				13
2	3		1	1	2														1	20
																				1
									1											1
		1																		4
		1																		8
		1										1								6
						2														3
	1	1																		5
2	1		1									1								17
																			4	4
1								1	1									2		13
					1	1										1		2		16
2	3			1	1													1	1	23
	1				1	1							1				1			18
								1	6	8	2									43
								1	13	12	5									55
2	1			1	1	6									1	2	1		1	22
						2	1	2			2		1	3	1					14
								2	5	1	2		1	17						33
1	1																			5
																				2
					3															10
				4		12	10	3	16	11	6		9	6	9		8			137
									5	10	3		2			9				32
									5	14	2									21
										13	6									20
									7	13	6			1						56
15	13	8	19	11	1												10	19	18	261
												12			4	3				19
1																			1	9
																				1
													1		1	5				7
						5	12	14	1	2	13	9	11	11	5					111
																				6
																				2
									1	1										3
							4	10	1		4	3	13	5	3					50
															4					6
	2	**3**		**1**												**1**	**2**		**1**	**52**

Appendix 4: Transect 3 (bearing 325 degrees): species cover score over 10 m lengths (Max. score 20); shown listed in Table 2 + 9 other spp. (*Banksia robur*, *Leptospermum liversidgei*, *Blechnum indicum*, *Gleichenia dicarpa*, *Phragmites australis*, *Baloskion tetraphyllum*, *Baumea rubinosa*, *Empodisma minus* & *Gahnia sieberiana*)

Distance (m)	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**230**	**240**
Height of surface (m)	**4.3**	**4.6**	**5.5**	**6.8**	**7.1**	**7.1**	**7**	**7.1**	**7.1**	**7.1**	**7.3**	**7.3**	**7.4**	**7.3**	**7.4**	**7**	**6.7**	**5.7**	**4**	**3.2**	**2.9**	**2.7**	**2.6**	**2.7**
Water table depth (m)	**0.3**	**0.4**	**1**			**2.8**	**2.8**		**2.7**			**2.8**				**2.5**		**1.3**	**1**	**0**	**0**	**0**	**0**	**0.1**
Tallest tree height (m)			**10**	**20**	**30**	**30**	**20**	**6**	**20**	**20**	**10**	**20**	**25**	**20**	**20**	**6**	**8**	**7**	**5**	**8**	**8**	**5**	**5**	**6**
(i) Tree species																								
Corymbia gummifera			1	3	5	5			2	12							3	4						
Eucalyptus pilularis				8	20	5	16					9	4	3	15									
Eucalyptus robusta																				7	12	1	6	6
(ii) Banksia species																								
Banksia aemula				1	2		7	8		7	11		5			5	2	6	4					
Banksia robur	2	5	1																		1		3	
Banksia serrata													1	2										
(iii) Myrtaceous shrub spp.																								
Callistemon citrinus	8	1																		1	3	1	4	12
Leptospermum juniperinum	2	7	5																	6	14	4	7	4
Leptospermum liversidgei	15	10	5																					
Leptospermum polygalifolium			2																6				2	
Leptospermum trinervium						1			1	2			3	4	3	11	6	1						
(iv) Other shrub species																								
Acacia suaveolens				4	2		1	2	2		3	1		2										
Acacia ulicifolia										2	2	1	1	1	2	1		1	2					
Bossiaea heterophylla				5	1	3	1	3	4	4		2	5	7	4	3	1	2	1					
Bossiaea rhombifolia					1	4	5	4	1	1														
Brachyloma daphnoides								2	4	2	1			4	2	1	1							
Dillwynia glaberrima				1			2		1	2	3					1	1							
Dillwynia retorta																		1						
Eriostemon australasius												1	1	1		2								
Gonocarpus teucrioides				1	1		1	1	1	1						3		1	1					
Hibbertia fasciculata																			1					
Hibbertia obtusifolia				2	3	1	2	2	1	3				1	1		2	3	3					
Leucopogon ericoides												1							1					
Leucopogon parviflorus																								
Leucopogon virgatus				2		2	1	2	1	1	1					2	1							
Monotoca scoparia					1	2		1	2				1	2	1									
Phyllota phylicoides				2																				
Pimelea linifolia						4					1						1		1					
Platysace linearifolia				4	1		1	6	3	1	7	1	1	4		5	1	6	6					
Ricinocarpos pinifolius				1		1	3	1	2	2	1	1		1	1	3			2					
Zieria laevigata							1																	
(v) Pteridophytes																								
Blechnum indicum	1	6	10																	12	5	1	5	4
Gleichenia dicarpa	5	18	6																	7			3	11
Pteridium esculentum			2	2	2		2	1	1	2	4	2	5	1	1		2		6	2				
Selaginella uliginosa																								
(vi) Grasses & lilies																								
Dianella caerulea																								
Entolasia stricta	4	10	6																	4	2	2	4	3
Panicum simile								1			3	2	2				1		1					
Phragmites australis																								
Themeda australis				3	1	4	4	8	3	3	8	1	3	2	5	3	8	7	2					
(vii) Restiads, sedges & lomandra																								
Baloskiontetraphyllum	2	3	12	1															5	15	19	10	13	20
Baumea arthrophylla		6	1																	2	13	4	4	6
Baumea rubinosa	4	1																		2	10	18	17	6

250	**260**	**270**	**280**	**290**	**300**	**310**	**320**	**330**	**340**	**350**	**360**	**370**	**380**	**390**	**400**	**410**	**420**	**430**	**440**	**450**	**460**	**470**	**480**	**490**	**500**	Total cover score
3.6	**4.9**	**5.6**	**6**	**6.2**	**6.4**	**6.6**	**6.7**	**6.8**	**6.7**	**6.6**	**6.5**	**6.3**	**6.1**	**5.9**	**5.9**	**5.6**	**4.2**	**2.1**	**1.7**	**1.6**	**1.3**	**0.8**	**0.4**	**0**	**0**	
1.4	**1.4**		**2**	**2.6**								**2.6**			**2.1**		**1.4**	**0.7**	**0.9**	**0.5**	**0.3**	**0.8**	**0.5**	**0.1**	**0.2**	
6	**30**	**30**	**15**	**25**	**25**	**25**	**30**	**10**	**25**	**25**	**25**	**30**	**30**	**25**	**25**	**25**	**15**	**20**	**10**	**10**	**6**	**8**	**10**	**4**		
																										Total
		12	11	10		2	4					7	4	8	20	19	5	6								143
	9	18		1	19	11	7		6	18	12	9	9													199
2																		1	9	16	3	4	7	3		77
		3	5				7				6	6		5	6	7	9	2								114
1																						6	4			23
								4	2		6	3														18
1																					1					32
6																				3	7	16	9			90
																				2	6	3	1			42
2	7	1		1														4	7							32
		2	2	4	3	6	3	10	11	7	12		4	2		2										100
		2	3	3	6	2									1											34
							1																			14
1	1	4	3	2	1	1	3	4		3		2			1		1	2								75
					1					1	1	3	1													23
															1											18
																										11
		5		1			1			1							2									11
			3	2		1	2	2	2	3	3	1			2	1		2								29
									1			2		2			1									17
												2														3
		2	2	1	1	2	2	1		2	1															38
																		2								4
	2		1								3							1								7
											1			1	1											16
		2		1				1	1		1			1				1								18
				1	2	3	2	2					3													15
																										7
	2		4	6	2	2	2	3	4	5	3	3	2	3	7	4	1	1								101
		4	5	3	1	1	3		2		3	2	4		2	2	2	1								54
																										1
8																			3	8		4	12	13	15	107
4																					7	5				66
1	1	1	4		1	2	3	2	5		6	2	1		3	3	3	4	1	1	1	2				82
																						1				1
	2	2			1														2	1						8
4																			4	16	3	8	12	2		84
														2	2											14
																								3	8	11
		2				3	8		3	2		3	1	9	5	3	1									105
13	7	2															4	8	17	13	1	8	4			177
																					2					38
																				3	14	11	10	20	19	135

Distance (m)	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**230**	**240**
Height of surface (m)	**4.3**	**4.6**	**5.5**	**6.8**	**7.1**	**7.1**	**7**	**7.1**	**7.1**	**7.1**	**7.3**	**7.3**	**7.4**	**7.3**	**7.4**	**7**	**6.7**	**5.7**	**4**	**3.2**	**2.9**	**2.7**	**2.6**	**2.7**
Water table depth (m)	**0.3**	**0.4**	**1**			**2.8**	**2.8**		**2.7**			**2.8**				**2.5**		**1.3**	**1**	**0**	**0**	**0**	**0**	**0.1**
Tallest tree height (m)			**10**	**20**	**30**	**30**	**20**	**6**	**20**	**20**	**10**	**20**	**25**	**20**	**20**	**6**	**8**	**7**	**5**	**8**	**8**	**5**	**5**	**6**
Chorizandra sphaerocephala																							4	1
Empodisma minus	17	12	2																				6	
Gahnia sieberiana	8	10	1																				3	2
Hypolaena fastigiata				11	8	1	1		1	4	3			2	3	6	1	9	2					
Lomandra glauca								1		2				1	1									
Lomandra longifolia										1		2				1			2					
Sporadanthus interruptus			6																	2				
(viii) Subshrub & herbs																								
Pomax umbellata								1	1	2	3	4	3	1			3							
Villarsia exaltata			2																		1	3	1	
(ix) Xanthorrhoea																								
Xanthorrhoea fulva		1	5	2													4	2						
Xanthorrhoea glauca					2																			
Bare ground						**1**	**2**	**2**	**3**	**2**	**1**	**1**			**1**			**3**						

Appendix 5. Species not recorded in standard transects (see Appendix 1), mostly encountered in long transects.

Species	**Transect / position**
Caleana major	4 / 100–200, 300, 500–550 m
Cassytha glabella	4/700
Cassytha pubescens	4/700
Comesperma defoliatum	1/85 m
Endiandra sieberi	4 / first 10 m
Macarthuria neo-cambrica	c. 900 m near Tr. 4 (collected Jan 2010)
**Spartothamnella juncea*	2/50–80 m & 3/10–20 & 470–480 m
Styphelia sp.	4 / 650–700, 1150 m
Xylomelum pyriforme	5/330 m

* possibly *Durringtonia paludosa* (Steve Griffith pers. com.)

250	**260**	**270**	**280**	**290**	**300**	**310**	**320**	**330**	**340**	**350**	**360**	**370**	**380**	**390**	**400**	**410**	**420**	**430**	**440**	**450**	**460**	**470**	**480**	**490**	**500**	
3.6	**4.9**	**5.6**	**6**	**6.2**	**6.4**	**6.6**	**6.7**	**6.8**	**6.7**	**6.6**	**6.5**	**6.3**	**6.1**	**5.9**	**5.9**	**5.6**	**4.2**	**2.1**	**1.7**	**1.6**	**1.3**	**0.8**	**0.4**	**0**	**0**	
1.4	**1.4**		**2**	**2.6**								**2.6**			**2.1**		**1.4**	**0.7**	**0.9**	**0.5**	**0.3**	**0.8**	**0.5**	**0.1**	**0.2**	
6	**30**	**30**	**15**	**25**	**25**	**25**	**30**	**10**	**25**	**25**	**25**	**30**	**30**	**25**	**25**	**25**	**15**	**20**	**10**	**10**	**6**	**8**	**10**	**4**		
																										Total cover score
																					1					6
																				6	11	2				56
																				2	15	3				44
		11	16	4		1	2		2	3	4	6	7	12	8	4										132
																										5
									1	2		1						2	1							13
	5																1	2		5	1	3	1			26
																										18
																										7
																										14
						1	6						1													10
	1	**1**	**1**		**1**	**1**		**2**	**1**			**2**	**2**					**4**	**1**							**33**

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Further observations on ecology of *Blandfordia cunninghamii*: flowering responses to rainfall and fire, and juvenile growth rates

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Abstract: A population of 700 *Blandfordia cunninghamii* Lindl. (family Blandfordiaceae) plants in the Blue Mountains, 100 km west of Sydney, New South Wales was monitored over a period of seven years, during which a part of the population area was burnt in a Hazard Reduction Burn (HRB). The survey measured flowering of *Blandfordia cunninghamii* in both the burnt and unburnt areas. In part of the unburnt area flowering (in December) was strongly correlated with previous September rainfall, but in another unburnt area there was no flowering at all over the seven years. An enhanced flowering response after fire was found in the burnt area and the diminution of this enhanced response in subsequent years was found to be logarithmic (taking into account potential rainfall effects). No recruitment of juvenile plants after fire was observed. 87% of seeds of *Blandfordia cunninghamii* were found to be germinable. Slow juvenile growth of *Blandfordia cunninghamii* in the field was measured over seven years. Seed was collected for two major seedbanks, the NSW Plantbank at the Australian Botanic Garden, Mt Annan and the Millennium Seedbank at Kew in the United Kingdom.

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Introduction

Blandfordia cunninghamii Lindl. (family Blandfordiaceae) is one of four *Blandfordia* species in Australia, all confined to the eastern states; three on the mainland, and one in Tasmania. All are known colloquially as Christmas Bells. All three mainland species occur in New South Wales. *Blandfordia nobilis* Sm is endemic in coastal regions south of Sydney (34° S) to about Bega (36° S). *Blandfordia grandiflora* R.Br ranges from Sydney to Fraser Island in Queensland (24° S), including occurrences in the lower and middle Blue Mountains (Porter et al 1992; Johnson 1998). *Blandfordia cunninghamii* Lindl. is a tufted perennial herb with leaves up to 1 m long. It is a rare species (Briggs & Leigh 1995) and is restricted to a narrow range of habitats in the Blue Mountains (lat 33° 40’ S, long 150° 20’ E) and the Illawarra areas of eastern New South Wales (Porter 1992).

While fire response of many other genera are known (eg see Campbell and Clarke 2006; Croft, Hofmeyer and Hunter 2006; Keith 1996; Pyke 1983) field data on fire responses have only been published for *Blandfordia nobilis* (Johnson 1998; Johnson 1996; Johnson Morrison and Goldsack 1994). In Coleby (2006) we investigated distributional and ecological aspects of *Blandfordia cunninghamii* but did not document flowering in response to fire. Since 2004 we have monitored a *Blandfordia cunninghamii* population in south Leura (Cliff View Road) in the upper Blue Mountains over a period of seven years allowing us:

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to compare the seasonal flowering responses with rainfall records,

to measure the flowering response in a burnt part of the population

to collect seed for germination testing, and

to monitor a trial planting of 12-month old seedlings in the natural environment over seven years.

This paper provides a summary of our results.

Methods

Location and fire history

The Cliff View Road *Blandfordia cunninghamii* population (GDA map reference 535649 on 1:25,000 Katoomba 8930–1–S topographic map, Lat 33º 43' 36.5", Long 150º 20' 23", elevation 910 m) (Figure 1) contains nearly 700 plants in the area of south Leura in the upper Blue Mountains and is part of the total population of 4300 plants of *Blandfordia cunninghamii* described in Coleby (2006).

The Cliff View Road population inhabits a steep hillside of average slope 30 degrees with a southerly aspect; both distinguishing features of populations of *Blandfordia cunninghamii*. It lies halfway down the 200 m slope between Cliff View Road in the north and Dundas Creek in the south, both of which have east-west alignments. The population lies at an altitude of about 910 m, in an east-west arc about 250 m long x 40 m wide, which dips in the west towards westward-flowing Dundas Creek. The eastern portion of the population lies in two private properties north of Leura Golf Club's dam on Dundas Creek. The remainder to the west lies in the Blue Mountains National Park. The unmade Carleton Road Reserve (10 m wide) runs north and south up the 30 degree slope and divides private property from National Park.

Part of this *Blandfordia* population was burnt in a Hazard Reduction Burn (HRB) in April 2008 which burnt the shrub understorey almost completely but only singed the eucalypt canopy. National Parks and Wildlife Service (NPWS) categorised the HRB as a cool burn, not as hot as a natural bushfire. The Cliff View Road Population in our study is divided into three areas (Figure 1):

Sub-Population 1a, unburnt (250 plants on either side of the burnt area)

Sub-Population 1b, burnt in April 2008 (250 plants in a block 60 m long (E–W) and 40 m wide (N–S), i.e. 2400 m^2)

Sub-Population 2, unburnt (200 plants).

Sub-Populations 1a and 1b occupy habitat within Blue Mountains Sandstone Plateau Forest (Map Unit 9i Keith & Benson 1988). The dominant canopy species are *Eucalyptus piperita* subsp. *piperita* and *Eucalyptus sieberi*, plus occasional *Eucalyptus dendromorpha* and *Eucalyptus stricta.* The shrub storey is largely *Leptospermum trinervium*, *Banksia cunninghamii, Banksia serrata,* and *Hakea dactyloides,* with *Callicoma serratifolia*, *Petrophile pulchella* and *Lambertia formosa.* The understorey includes *Epacris microphylla*, *Olearia myrsinoides*, *Lomatia silaifolia, Lycopodium deuterodensum* and *Gahnia microstachya.*

Population 2 is closer to Dundas Creek and occupies a markedly different habitat to that of Population 1: its landform is a series of short steep cliffs (3–5 m high) on which *Blandfordia cunninghamii* are a dominant component of vegetation. The slopes adjoining the Creek are much more shallow than the usual 30 degree preference of *Blandfordia cunninghamii*, and the vegetation exhibits aspects of cool temperate rainforest with *Pteridium esculentum*, *Gleichenia dicarpa* and *Callicoma serratifolia*.

Recording of flowering and seedlings

The boundary of the population in the investigation was slightly larger than the 662 plants recorded in 2004 because 38 more outlying plants had been subsequently identified. An old power pole on Carleton Road on the north-south boundary between National Park and private property was used as a datum from which the population extends 80 m east into private property, and 170 m west and then south into National Park.

The entire population was surveyed using 100 contiguous 10 x 10 m quadrats encompassing every plant and every flower stem, though not every quadrat contained *Blandfordia cunninghamii* plants. Field recording was conducted in the six summers of 2007–08 through 2012–13. Each year we counted flower stems, usually in late December after the peak of each flowering season. The counts included flower stems that had gone to seed and late stems with buds. The prominence and persistence (many stems persist for a year or more) of all stems up to 80 cm tall made identification easy.. We checked later in each season that no new stems had appeared. Each year at the same time we searched for evidence of recruitment of *Blandfordia* seedlings.

Seed collection

Richard Johnstone (NSW Seedbank Officer, Australian Botanic Garden, Mount Annan) took advantage of enhanced flowering in 2008–09 to collect nearly 20 g of seed with the assistance of the author. The collection was made in mid-March 2009, at a time when at least 90% of the available seed had already been shed into the environment.

Seedling propagation and growth

Prior to this study seeds of *Blandfordia cunninghamii* had been collected from a private property in south Leura and propagated in a nursery in December 2005. In December 2006 25 seedlings from this collectiom, each with 3–4 leaves about 30 mm long and less than 1 mm wide, were planted out in south Leura on a southern slope at a location separate from that surveyed above. This location had similar native vegetation with 9i Open Forest as above, and was chosen because it was within an existing population

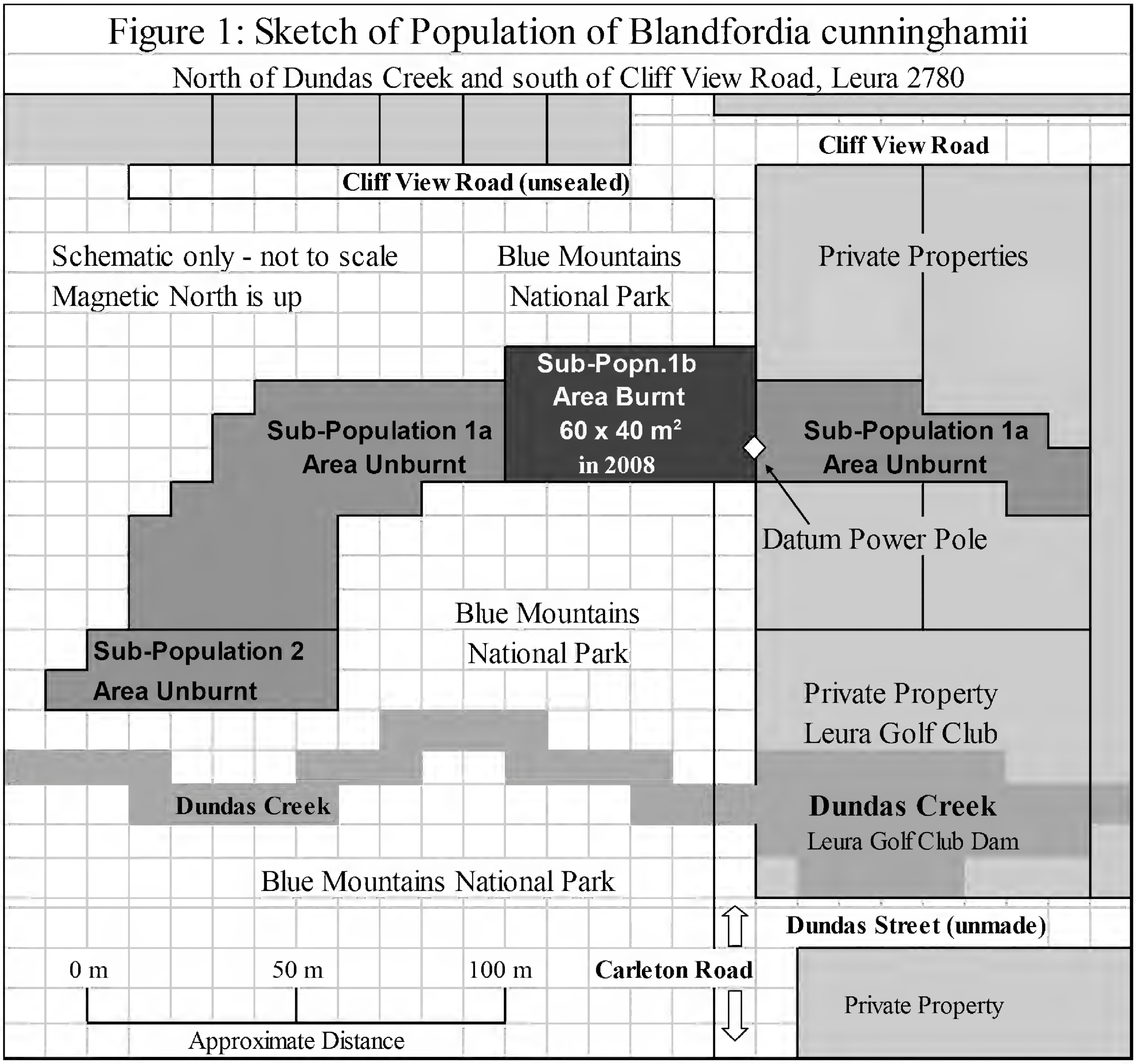
Figure 1: Sketch of Population of Blandfordia cunninghamii
North of Dundas Creek and south of Cliff View Road, Leura 2780
Cliff View Road
Cliff View Road (unsealed)
Schematic only - not to scale
Magnetic North is up
Blue Mountains National Park
Private Properties
Sub-Popn.1b Area Burnt 60 x 40 m2 in 2008
Sub-Population 1a Area Unburnt
Sub-Population 1a Area Unburnt
Datum Power Pole
Blue Mountains National Park
Sub-Population 2 Area Unburnt
Private Property Leura Golf Club
Dundas Creek
Dundas Creek
Leura Golf Club Dam
Blue Mountains National Park
Dundas Street (unmade)
0 m
50 m
100 m
Carleton Road
Private Property
Approximate Distance

Fig. 1. Location of subpopulations of *Blandfordia cunninghamii* at Cliff View Road Leura.

of mature *Blandfordia cunninghamii*, thus guaranteeing suitable habitat. The seedlings were planted at 2 m intervals in a five-by-five array, with minimum disturbance to the environment, each marked with a white topped bamboo cane for easy identification. There was no further treatment of the seedlings in the field.

Rainfall

Rainfall was measured daily over the seven-year period at a site 300 m southeast of and at the same elevation as the Cliff View Road population. These data were used in preference to the Bureau of Meteorology (BoM) official figures because rainfall patterns in the Blue Mountains are highly variable, and the nearest BoM recording station is at Mount Boyce, 13.5 km northwest of the Cliff View Road population.

Results

Effect of rainfall on flowering

Over a ten year period no flowering was recorded for any of the 200 (unburnt) Population 2 plants. In contrast some flowering was recorded in every year in the similarly (unburnt) Sub-Population 1a plants which presumably received the same rainfall. For Sub-Population 1a, Table 1 shows the number of flowering stems recorded each year in late December (for the period January 2007 to December 2012) and the locally-recorded monthly rainfall totals over the same period, together with correlation coefficients between the annual number of flowering stems (first column) and total rainfall for each separate month of the year (bottom line).

Table 1. Number of flower stems per year in Sub-Population 1a and correlation with rainfall (mm) in each month for the years 2007–2012, September was the one month where a correlation coefficient (0.92) was significant (at the 1% level).

No.of Stems	Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
	Year													
8	2007	68	314	167	66	51	403	22	139	47	24	370	202	1873
16	2008	162	245	62	163	9	153	39	39	105	94	79	73	1223
7	2009	33	278	57	213	166	49	42	21	22	168	42	109	1200
6	2010	125	465	93	25	108	104	79	66	42	142	184	188	1621
18	2011	162	84	173	103	99	136	46	34	125	95	191	158	1406
1	2012	203	233	284	131	23	142	40	17	33	32	62	61	1261
Correlation Coefficient		**0.1**	**-0.55**	**-0.4**	**0.1**	**-0.05**	**0**	**-0.1**	**-0.03**	**0.92**	**0.15**	**0.12**	**0.2**	**0.1**

September was the one month where a positive correlation coefficient (0.92) was significant at the 1% level. Regression of the number of flower stems (Column 1 of Table 1) against September rainfall for that year is shown in Figure 2.

Effect of fire on flowering

The April 2008 burning of the 250 plants in Sub-Population 1b had an immediate effect on flowering in the following season with the number of flowering stems increasing from 4 in 2007 to 115 in 2008, followed by irregularly diminishing numbers in succeeding years (Table 2, Figure 3). The possibility that subsequent flowering might have been enhanced by a smoke effect on the plants during the burn was considered, but no evidence was observed. Indeed, mature plants only 1m from the edge of the burn showed no increase in flowering, and observations suggested that even plants that were singed on the edge of the burn exhibited no increase in flowering. The possibility that subsequent flowering might have been enhanced by nutrients arising from higher up the slope percolating downwards to an unburnt part of the population was also considered but observations did not support this.

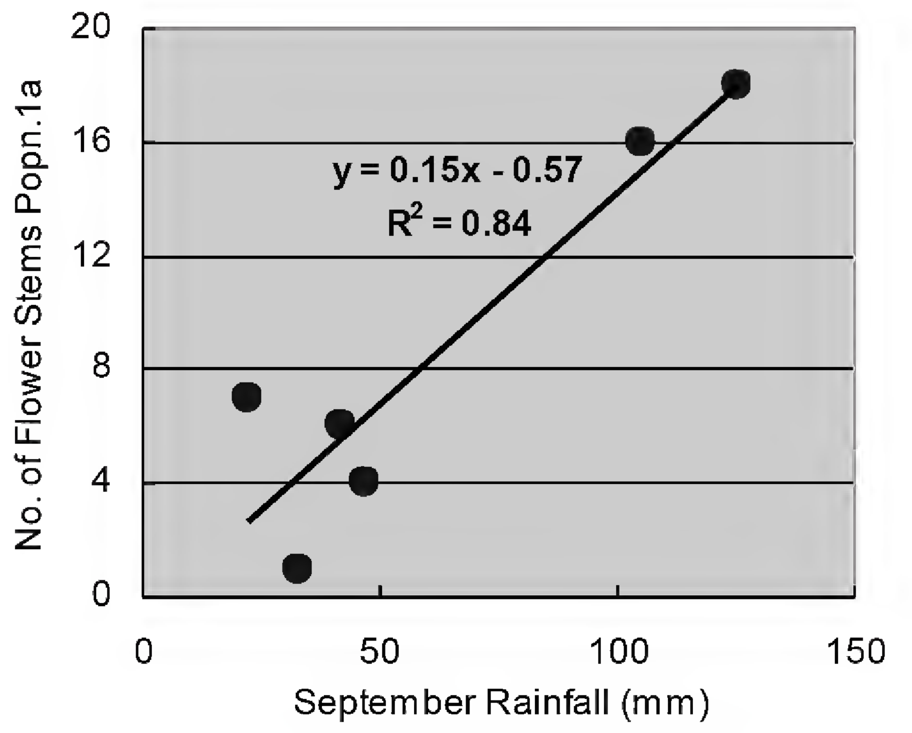

Fig. 2. Linear regression of the number of flower stems recorded annually in December (2007–2012) compared with rainfall in the previous September for Sub-Population1a (unburnt) plants.

Table 2. Number of annual flower stems in Sub-Population 1b for period 2007–2012 (burnt in April 2008)

Year	Number of flower stems
2007	4
2008	115
2009	43
2010	13
2011	18
2012	3

A simple hypothesis is that in Sub-Population 1b the two effects of fire and September rainfall are additive and independent, and that the relationship is linear. In order to separate the fire response we subtracted the rainfall component from the total response shown in Table 2 and Figure 3. To do this we used the rainfall from Sub-Population 1a as a proxy for that in Sub-Population 1b, not using actual

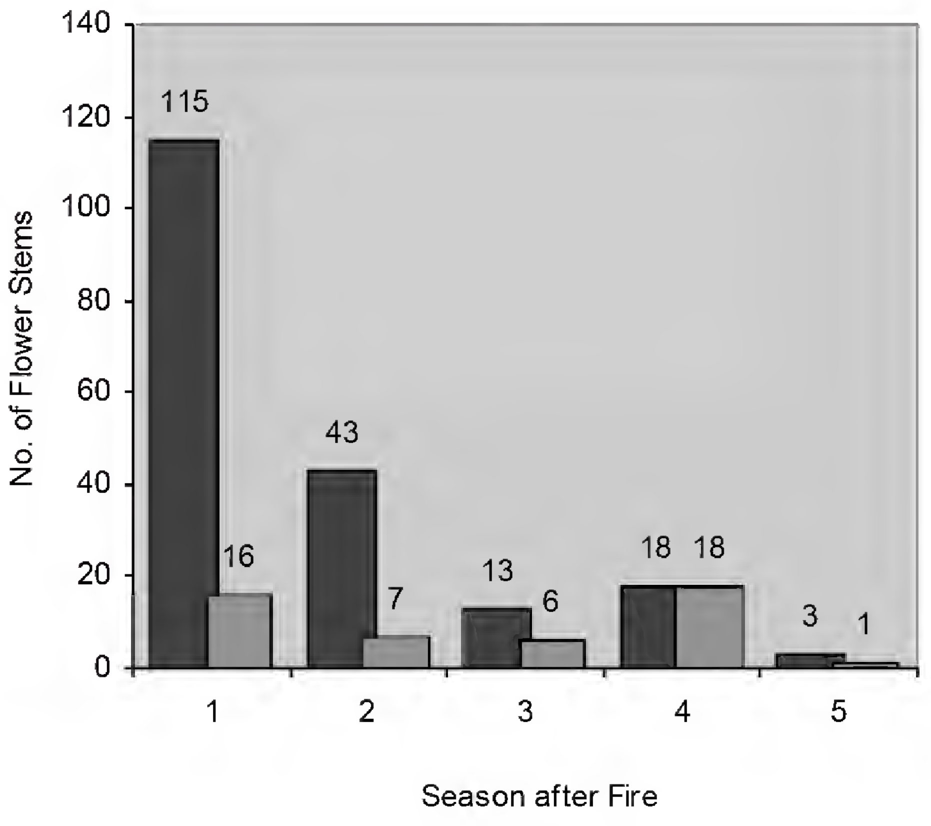

Fig. 3. Number of flower stems in Sub-Population 1b (■ burnt in April 2008) and Sub-Population 1a (▒ unburnt) in 2008–2012 (1–5) seasons.

Table 3. Separating the effects of fire and September rainfall on the number of flower stems in Sub-Population 1b (burnt in 2008). See text for explanation

1 Year	2 September Rainfall (mm)	3 Expectation y = 0.15x - 0.57 (from Fig 2)	4 Stems in Burnt Popn.1b	5 Difference Col 4-Col 3	6 Adjust Origin Col 5 + 2.5	7 Log 10 (Col 6)	8 Season After Fire
2008	105	15.18	115	99.82	102.32	2.01	1
2009	22	2.73	43	40.27	42.77	1.63	2
2010	42	5.73	13	7.27	9.77	0.99	3
2011	125	18.18	18	-0.18	2.32	0.37	4
2012	33	4.38	3	-1.38	1.12	0.05	5

values, but the *expected* values determined by the regression equation y = 0.15x – 0.57, from Figure 2. These expectations are shown in Column 3 of Table 3. The actual numbers of flower stems in the burnt Sub-Population 1b are shown in Column 4 of Table 3, and the difference between expectation and actual numbers is shown in Column 5. The two negative numbers in Column 5 were removed by adding 2.5 to all numbers in Column 5, and the adjusted numbers are shown in Column 6. This manipulation did not materially alter the outcome. We calculated the logarithm of these adjusted numbers, and show them in Column 7. Column 8 records the season after fire. We graphed Columns 7 and 8 of Table 3 in Figure 4.

We concluded from Figure 4 that there would be a semi-logarithmic relationship between the number of flower stems in any one year and the season after fire in the absence of any rainfall effect. The correlation coefficient of the data (r^2=0.994) is significant at the 0.1% level Over the five-year

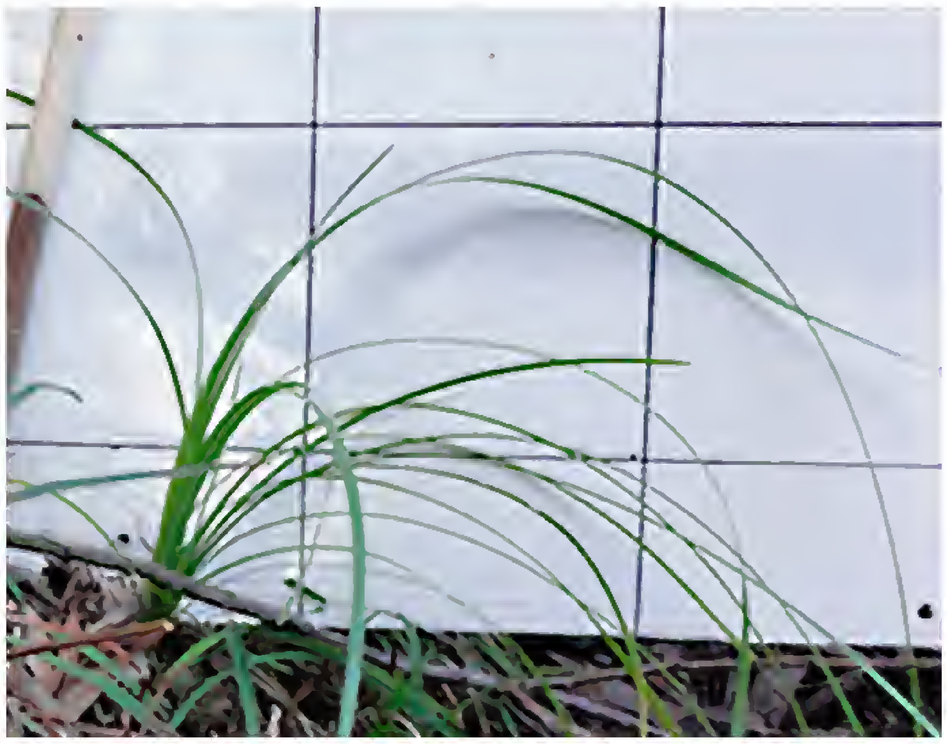

Fig. 5. (left) Immature *Blandfordia cunninghamii* (six years old) in natural environment (Scale = 10 cm)

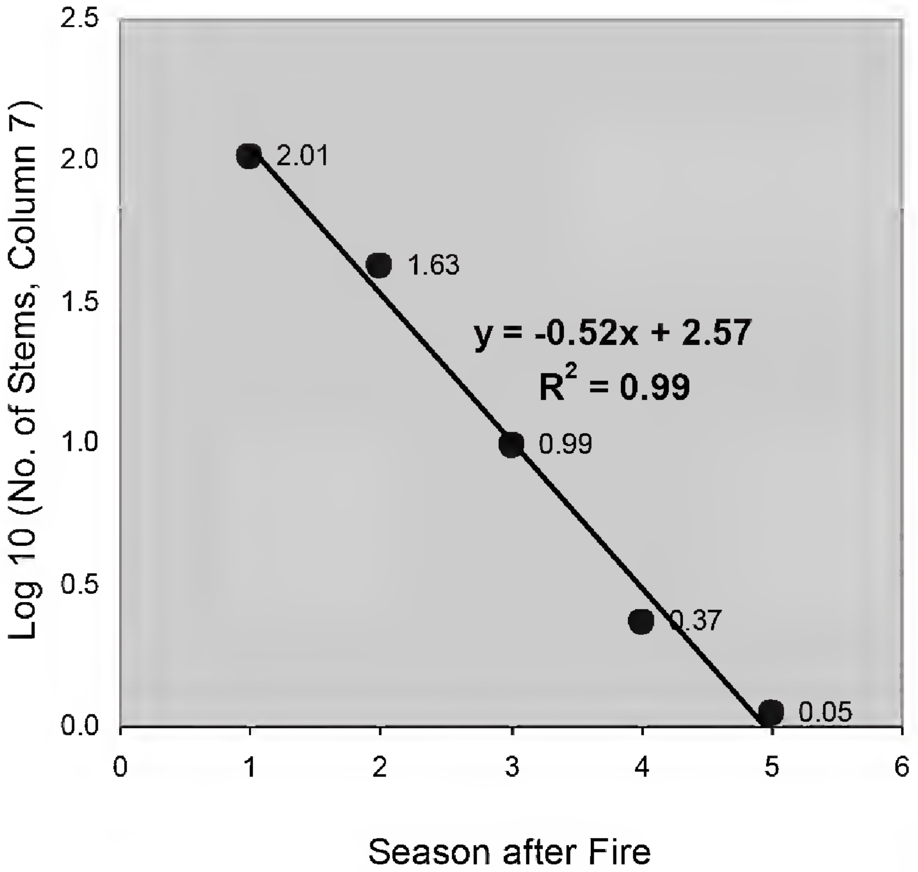

Fig. 4. Semi-logarithmic graph of adjusted numbers of flower stems in Sub-Population 1b (from Columns 7 and 8, Table 3), r^2 = 0.99; Slope = -0.52; Intercept = 2.57; y= -0.52x + 2.57

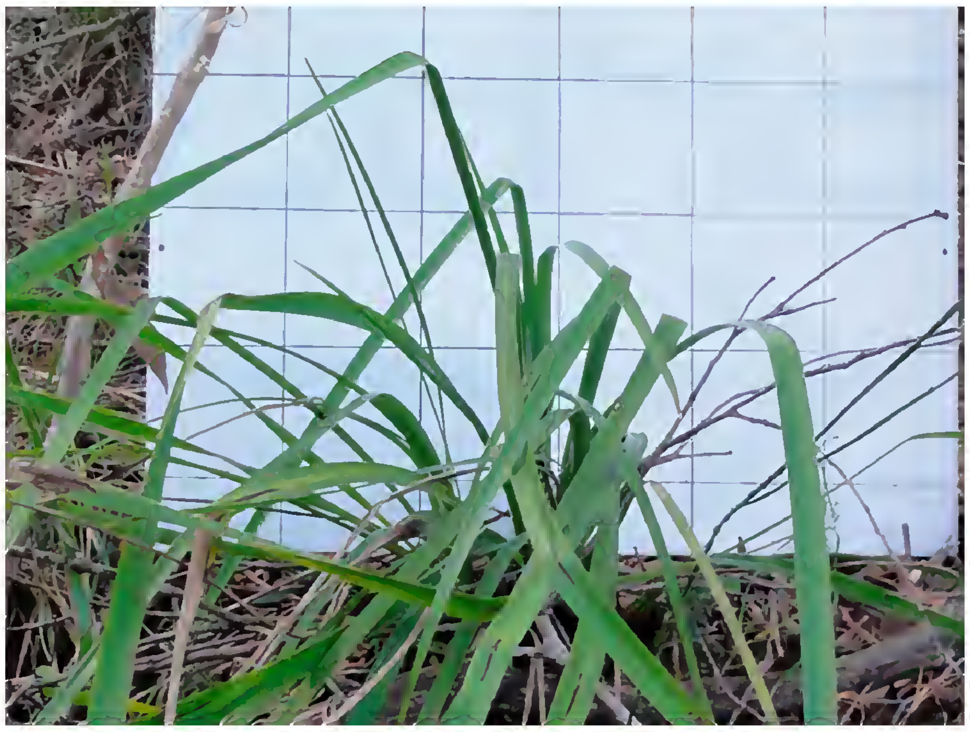

Fig. 6. (right) Mature *Blandfordia cunninghamii* (age not known) in natural environment (Scale = 10 cm)

period the slope of the semi-logarithmic decline is - 0.52, the equation of the line is $y = -0.52x + 2.57$, and $R^2 = 0.99$.

Seed collection and recruitment

Seed testing at the Australian Botanic Garden, Mount Annan showed that, after cleaning, the germination rate was 87%. The high measured germinability of fresh *Blandfordia cunninghamii* seed is likely to decline over time, even under controlled seed storage conditions, but the rate of that decline is unknown. Part of the seed was sent to the Millennium Seedbank at Kew Gardens, UK, and the remainder retained in the NSW Plantbank at the Australian Botanic Garden.

No recruitment of juvenile *Blandfordia cunninghamii* to the population was observed, either in the burnt portion or in the unburnt portion. Recruitment may have occurred, especially in the burnt portion, but was not detected because of small size of juveniles in the short time since the fire. Their small size renders them almost indistinguishable from similar leaves of other monocotyledons.

Seedling survival and growth

Twelve of the 25 seedlings planted in 2006 survived to May 2013, but their growth was slow. Only one plant (see Figure 5) showed significant development: it had 21 leaves (mostly between 300 and 410 mm length and about 2.5 mm wide). Among the other eleven plants the average number of leaves was 6; none was more than 450 mm long or more than 2.5 mm wide. The plants in Figures 5 and 6 inhabit the same sloping site, only 2 m apart.

Only the longest leaves exhibited the beginnings of two small veins, parallel to and on either side of the prominent central rib of the leaf. Leaves on mature plants (see Figure 6) are commonly up to 1 m long, 10–15 mm wide, with 8–15 distinct veins on either side of the central rib. These observations suggest that recruitment to maturity is a slow process, probably measured in decades.

Discussion

The results show that fire appears to promote flowering in *Blandfordia cunninghamii* in the season immediately following fire, but neither nutrient transfer nor smoke exposure had any noticeable effect on plants outside the burn area. The maximum response occurred when the plants themselves were burned, removing all leaves and leaving only a charred but intact hypocotyl at or below ground level. Population flowering response to a fire stimulus was not limited to the flowering season immediately following fire. Enhanced flowering continued in subsequent years, but at a diminishing and highly variable rate (Figure 3). Over a period of five years the flowering rate in the burnt area (Sub-Population 1b) diminished to the point where it had reverted to background levels of 1–2% of plants flowering per year, as in the unburnt area (Sub-Population 1a). These observations are similar to those of Johnson, Morrison and Goldsack (1994) in relation to *Blandfordia nobilis.* In contrast, Pyke (1983) found that in the woody shrub *Telopea speciosissima* the percentage (or density) of plants in flower, the average number of flowers per inflorescence and the average number of fruits per inflorescence all appear to peak two years after a summer fire and decline thereafter. In the shrub *Lambertia formosa* Pyke (1983) also reported that the density of inflorescences reaches a peak 2 or 3 years after a summer fire. Woody shrubs such a *Telopea* and *Lambertia* are more likely to flower on older wood, whereas *Blandfordia* flower stems emerge directly from the hypocotyl.

Flowering response may also be influenced by a host of environmental factors such as the burn status (whether cool, intermediate or hot), the yearly variations in temperature and rainfall, the regeneration of canopy and other vegetation layers, and access to nutrients that might enhance flowering (Lamont et al 2000; Myerscough 2009; Pyke 1983). Considerations of this nature were mostly beyond the scope of this study.

An unexpected finding was the strong correlation ($r^2=0.92$) between the annual count of flower stems in unburnt Sub-Population 1a and total rainfall in September of that year. There is no obvious relationship with any of the other eleven months. Were September rainfall alone to be responsible for flowering then we would expect Sub-Populations 1 and 2 (where no flowering was recorded) to behave similarly. That they do not suggests that whatever flowering stimulus is present, it is not *direct* rainfall, in September or in any other month. This observation suggests that local habitat conditions play a part in flowering responses and may vary over the range of the species. For example September rainfall in Sub-Population 1 may provide access to the water table in that area, at a time when plants are receptive to a trigger for flowering later that year. In Sub-Population 2 the nearby creek dominates the water table, there is little variation in depth of the water table (it is well below the plants on the small cliffs) and the flowering stimulus is thus removed.

The seed germinability results are consistent with this author's earlier observation that at 75% of fresh *Blandfordia cunninghamii* seeds will germinate. In the natural environment, there are large numbers of seeds per capsule (~50) and of capsules per flower head (~25) (Coleby, 2004). However, recruitment of seedlings to juveniles and beyond is very low: seed and seedling mortality through predation by unknown vectors (but probably insects), competition from established plants, and/or lack of follow-up available water are probably dominant factors. Data collected in the present study indicate that seedlings may remain very small for several years, and thus difficult to recognise amid a welter of regrowth of other species after fire.

Summary

This study found a strong correlation ($r^2=0.92$) between September rainfall and flowering rate later that year for part of the Cliff View Road population of *Blandfordia cunninghamii.* Observations of habitat of different parts of this population suggest that this effect may not be brought about by direct rainfall itself, but by contact with the water table at a time when the plants begin to produce flower stems.

The study found that *Blandfordia cunninghamii* showed a marked response to fire as a stimulus to flowering in the first season after fire, much as reported for *Blandfordia nobilis* and other genera. This flowering response diminished in later years after fire: when the effects of variable September rainfall were removed, the diminution in flowering response was semi-logarithmic.

This study found that fresh seed, after cleaning, was 87% germinable but no natural seed recruitment was observed. It appears that plant development from seed to mature plants is a long process, probably measured in decades.

To paraphrase Frances Crick (quoted in Ridley 1999) "the arguments and assumptions which we have had to employ to deduce these results are too precarious for us to feel much confidence in them on purely theoretical grounds. We put them forward because they rest upon the correlations in a neat manner and from reasonable physical postulates."

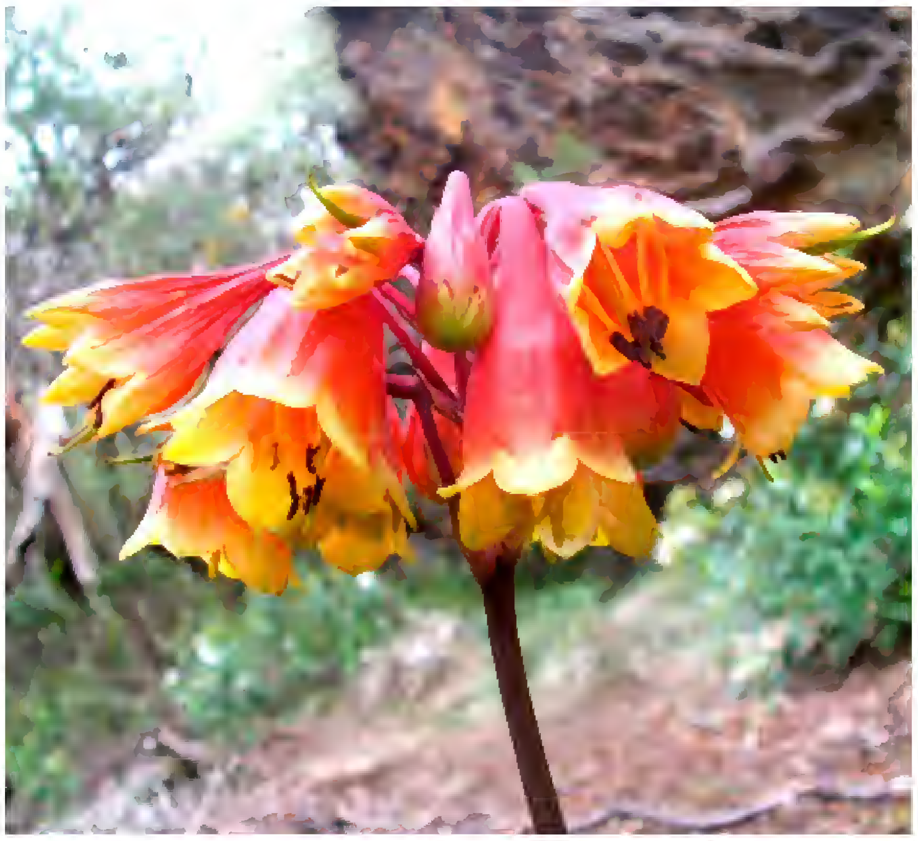

Fig. 7. The distinctive flowers of *Blandiflordi cunninghamii*

Acknowledgements

It is a pleasure to record my thanks to two Members of the Sublime Point Bushcare Group: the several years of field assistance by Ross Day, and the assistance in keeping rainfall records by Imre Gahl. I also acknowledge the cooperation of officers of the National Parks and Wildlife Service at Katoomba and Blackheath which enabled this survey to be conducted, and the cooperation of two private land-owners. Ready support was given by Richard Johnstone and Leahwyn Seed, NSW Plantbank Officers at the Australian Botanic Gardens at Mt Annan. I would also like to thank an anonymous referee for detailed comments on the manuscript.

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Ecology of *Eucalyptus aquatica* (Myrtaceae), a restricted eucalypt confined to montane swamp (fen) habitat in south-eastern Australia

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Abstract**:** The Paddys River Wetlands in the New South Wales Southern Highlands, southwest of Sydney, are characterised by several watercourses with associated swamps (fens), some of which, on Forestry Corporation of NSW land, have been the focus for removal of *Pinus radiata* wildings by the Penrose Swamps Conservation Group. In this study we map a population of *Eucalyptus aquatica* trees in one of these swamps perched above Paddys River (latitude 34.65575° S, longitude 150.21831° E; 600 m elevation). *Eucalyptus aquatica* is geographically restricted to the Paddys River area and is listed as a threatened species at state and national levels. New findings on the physical characteristics of the swamp in relation to the bedrock geology, stream geomorphology, peat development and the main native plant species, are presented.

The occurrence of clumps of *Eucalyptus aquatica* appears to be independent of the type or thickness of the growing substrate. Rather it is suggested that a continuous supply of water and the shelter afforded by the narrow valley may be key factors determining the distribution of the trees at the study site. An on-going programme of research is underway to study other occurrences of *Eucalyptus aquatica.*

Keywords: montane swamp, threatened species, peat depth, incised watercourse, Hawkesbury Sandstone.

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Introduction

Eucalyptus aquatica (Broad-leaved Sally) (family Myrtaceae) is a small tree known only from the Penrose area in the Southern Highlands of New South Wales where it occurs sporadically in swampy ground (Harden 1991; Benson & McDougall 1998; Australian Government 2008; NSW Office of Environment & Heritage 2012). Previously considered a sub-species of *Eucalyptus camphora* (Brooker & Kleinig, 1999), *Eucalyptus aquatica* was described as a separate species by Wiecek (2011). It is listed as a Vulnerable Species under both NSW State and Federal threatened species legislation (Australian Government 2008; NSW Office of Environment & Heritage 2012). The swamp (fen) habitats associated with *Eucalyptus aquatica* are also listed as Endangered Ecological Communities "Temperate Highland Peat Swamps on Sandstone" under the Federal *Environment Protection and Biodiversity Conservation Act* 1999 (Australian Government 2005) and "Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions" under the NSW *Threatened Species Conservation Act* 1995 (NSW Scientific Committee 2004).

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This study focuses on a local population of *Eucalyptus aquatica* in an (unnamed) montane swamp at 600 m altitude in Penrose State Forest, Penrose (latitude -34.656 E, longitude 150.218 S decimal degrees) (Figure 1). We have also recorded *Eucalyptus aquatica* in Hanging Rock Swamp, Stingray Swamp and a number of unnamed swamps on the valley sides of Paddys River within and around Penrose State Forest. The montane swamp habitat has been described as a peat forming fen (see Mactaggart, 2008; Keith, 2004 p.210; Kodela 1994; NSW Office of Environment & Heritage, undated) and a study of lower elevation but similar 'upland swamps or dells' on the Woronora Plateau near Wollongong (Young, 1982) suggested that these communities result from reduced permeability in some of the Hawkesbury Sandstone strata. The vegetation in all these swamps as typically treeless being dominated by shrubs and sedges, and the occurrence of a swamp-dependent eucalypt is quite unusual.

Like many threatened species, little is known of the ecology of *Eucalyptus aquatica*. Since 2008 Penrose Swamps Conservation Group has been working in Penrose State Forest removing weeds (predominately *Pinus radiata* wildings) and studying the factors influencing the occurrence of *Eucalyptus aquatica* in the swamps. This paper provides information on the distribution and occurrence of a local population and places the species' ecology into a geological and geomorphological context.

Methods

Swamp setting

The swamp studied is an (unnamed) montane swamp in Flora Reserve No. 97556 of Penrose State Forest, Penrose in the NSW Southern Highlands, southwest of Sydney (Figure 1). The State Forest is managed for softwood pine (*Pinus radiata*) production by Forestry Corporation of NSW. The swamp is bordered by a public road on two sides and is crossed by a forestry track (known as Webbers Road) at its western end (Figure 1).

The swamp is located on a tributary of Paddys River (latitude 34.65575° S, longitude 150.21831° E) (Figure 1), two kilometres to the south of Stingray Swamp. It is perched above the river and has a total length of approximately 1500 m (Figure 2). The lowermost 200 m segment of the swamp contains the *Eucalyptus aquatica* population, below Webbers Road and before the watercourse joins Paddys River. Surrounding vegetation includes mature *Pinus radiata* plantations and Eucalypt woodland (Figure 1). The site occurs within the Moss Vale 1:100,000 map sheet area.

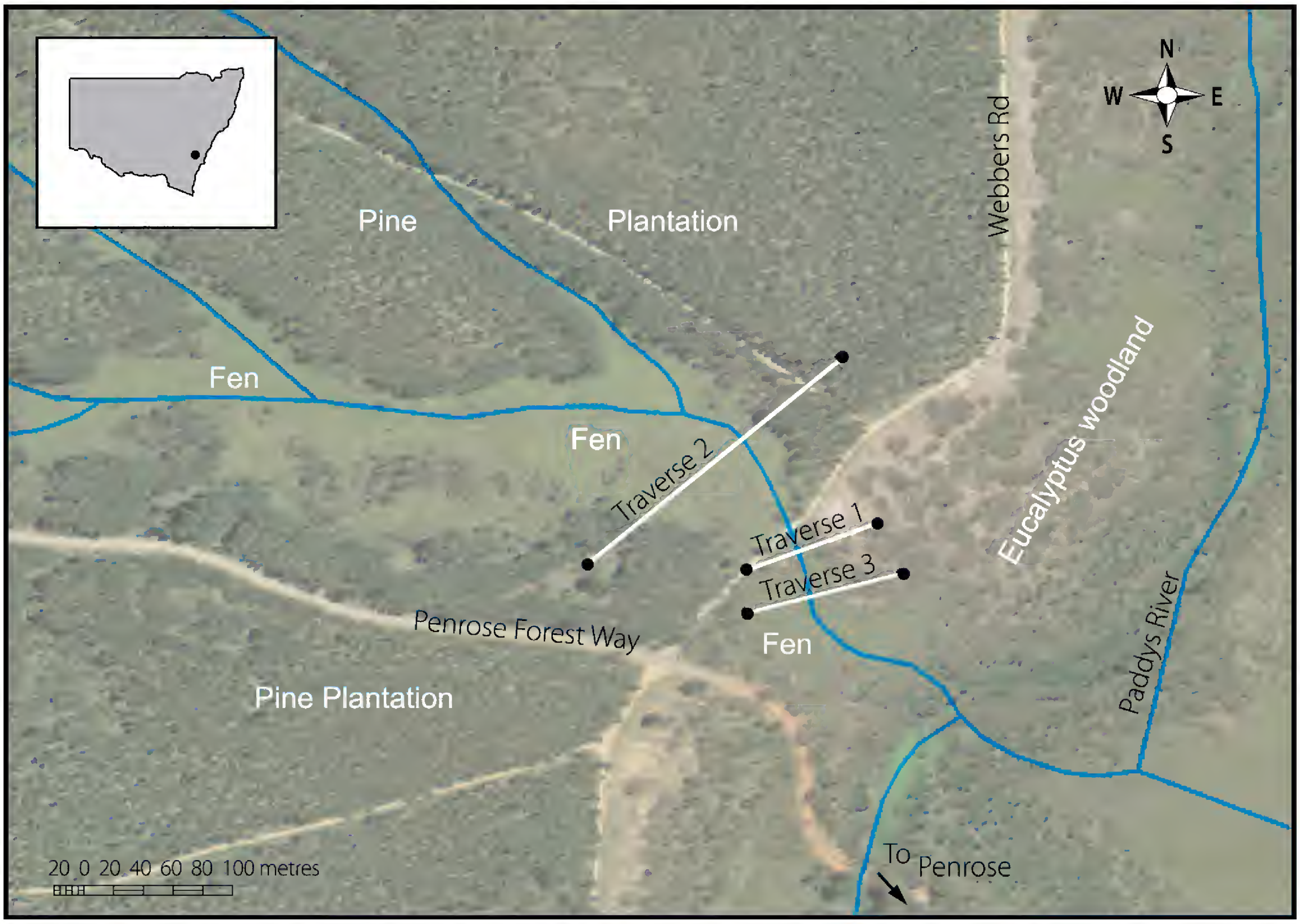


Fig. 1. Location of swamp study area in Flora Reserve, Penrose State Forest (including locality inset). Background imagery is ADS40 Moss Vale 1:100,000 (2008).

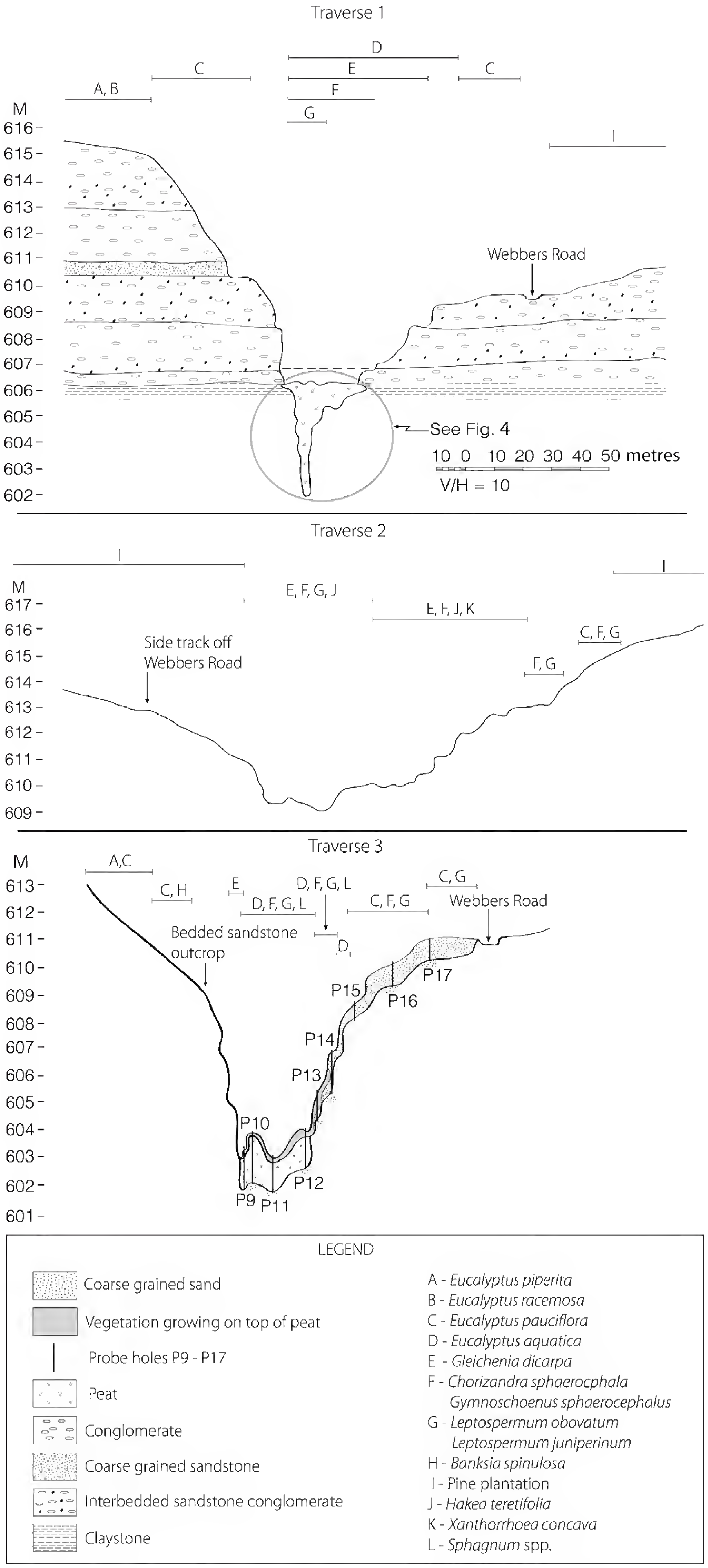


Fig. 2. Geological cross section of the gorge at Traverse 1 showing the deep, narrow peat deposit and occurrence of the main flora compared with cross section of Traverse 2 showing flora distribution, plus valley cross section of Traverse 3 showing peat deposits and flora distribution (Flora Reserve, Penrose State Forest).

Field mapping methods

Fieldwork was carried out in August 2012. Our mapping focused on the lower segment of the swamp where *Eucalyptus aquatica* is located. The locations of the approximately 350 *Eucalyptus aquatica* plants that occur in the swamp along with associated vegetation were mapped using a hand held GPS. Tree height, canopy width, tree trunk type (single or mallee habit), percentage green foliage present and tree condition were estimated for each tree. Tree condition was estimated visually by the recorder based on percentage canopy alive, (dead = 0, poor = 1–40%, moderate =41–75%, good >75%) to provide a baseline data set for future comparison (see Appendix 1).

Altitudinal data for each tree was taken at the top of the peat surface using an altimeter calibrated to a point of known nearby spot height on the Department of Lands 1:25 000 topographic sheet (2005), making it possible to measure altitudes to ± 1 m. Frequent checks were made to ensure that the altimeter was only used in stable meteorological (pressure) conditions. Distance versus altitude profiles were constructed from field measurements.

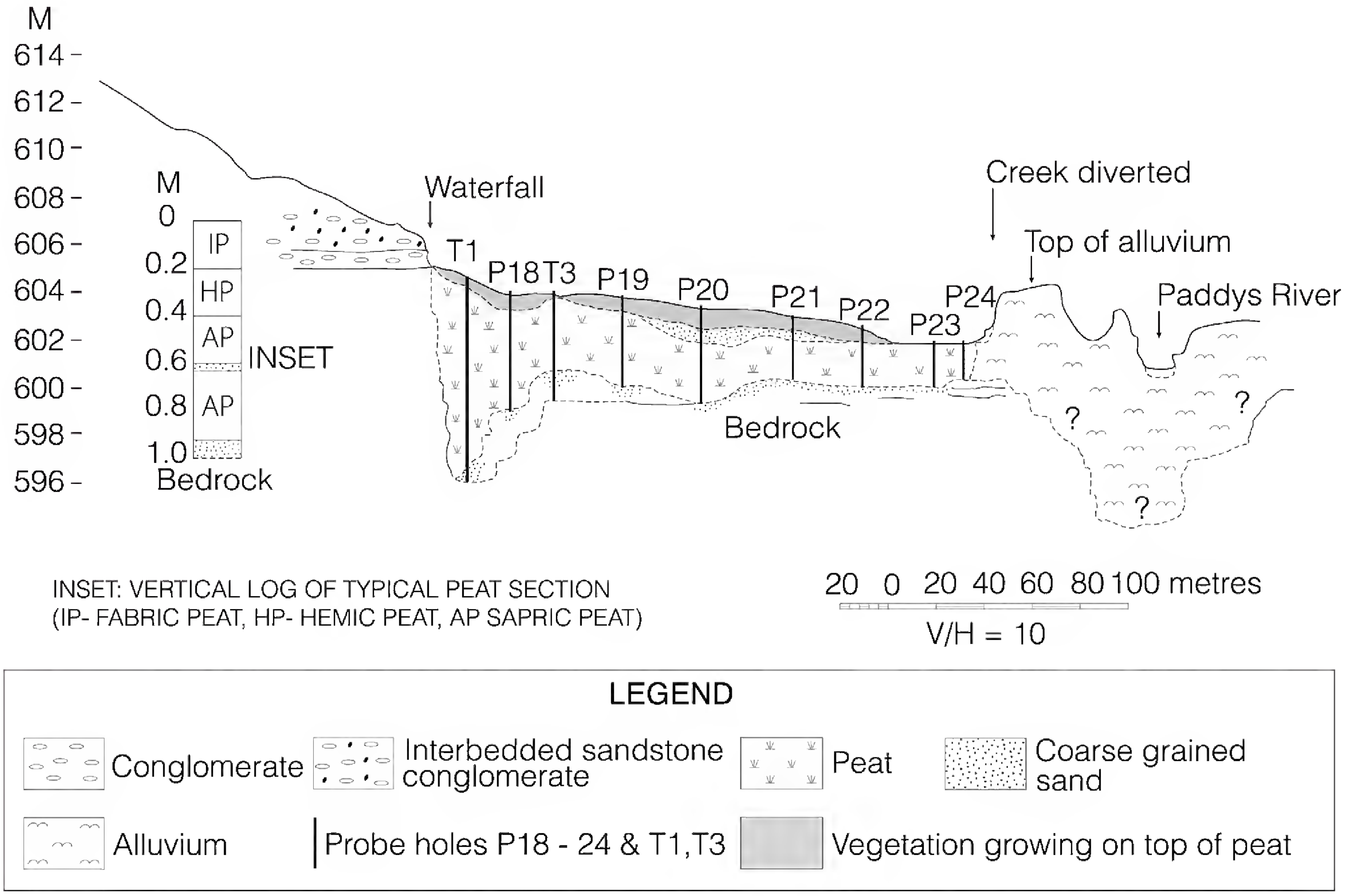
A peat probe (a form of penetrometer), which extends to 5.2 m, was used to map sandy horizons, peat type and peat depth, in some cases down to bedrock. The bedrock under the swamp peat was inferred from mapping in the valley sidewalls.

Three traverses (T1–T3) across the swamp were mapped on approximate bearings of 237° (TN), that is, from NE to SW. Two of these (T1 and T3) were across the stands of *Eucalyptus aquatica*. T2 was made for comparison upstream of Webbers Road, across the treeless sedges (Figure 2). In addition, a longitudinal traverse was made from just below Webbers Road to the lowest extent of the swamp. Mapping in the swamp was arduous work due to dense vegetation and wet peat conditions.

Results

Bedrock strata and geomorphologic features

Limited rock outcrops of the mid Triassic age Hawkesbury Sandstone form bare ledges on the northern side of the swamp (Trigg & Campbell 2011), whereas on the southern side sandstone benches are almost completely covered in vegetation (see Traverse 1 in Figure 1). This sandstone includes pebble conglomerates, inter-bedded and occasionally cross-bedded with coarse grained sandstones. Clearly observed bedding planes separate the strata of different grain sizes. Just above the swamp level, at an elevation of 609–610 m, a thin shale/claystone lens is present; it outcrops in a small quarry exposure that is used for local road-base material.


M
614
612
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M
0
0.2
0.4
0.6
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1.0
IP
HP
AP
AP
INSET
Bedrock
Waterfall
T1
P18
T3
P19
P20
P21
P22
P23
P24
Creek diverted
Top of alluvium
Paddys River
Bedrock
?
INSET: VERTICAL LOG OF TYPICAL PEAT SECTION
(IP- FABRIC PEAT, HP- HEMIC PEAT, AP SAPRIC PEAT)
20 0 20 40 60 80 100 metres
V/H = 10
LEGEND
Conglomerate
Interbedded sandstone conglomerate
Peat
Coarse grained sand
Alluvium
Probe holes P18 - 24 & T1,T3
Vegetation growing on top of peat

Fig. 3. Longitudinal section of the swamp showing the peat deposit and the fluvial deposits of Paddys River (Flora Reserve, Penrose State Forest).

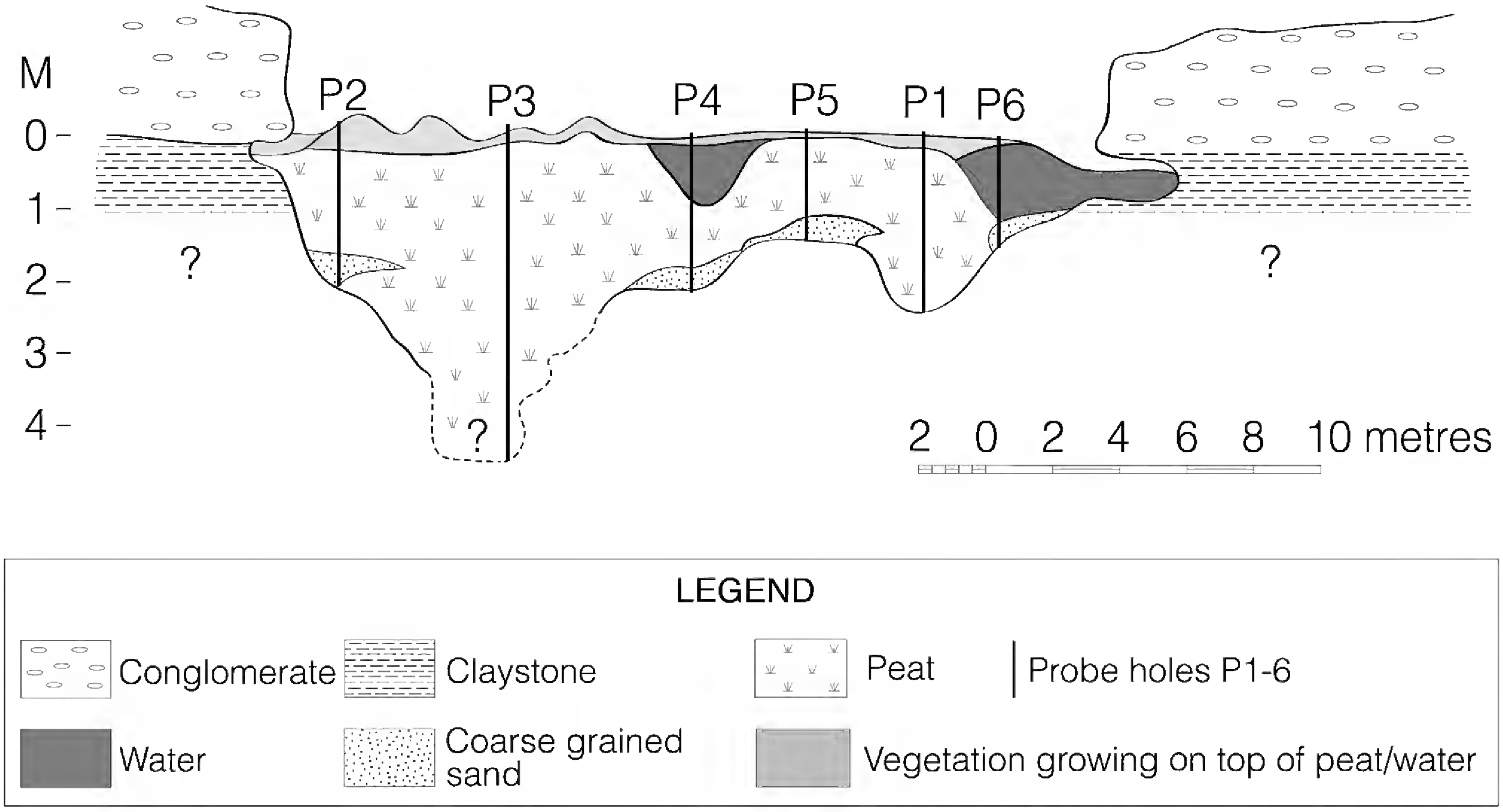

Fig. 4. Detailed cross section of the peat deposits along Traverse 1 (Flora Reserve, Penrose State Forest).

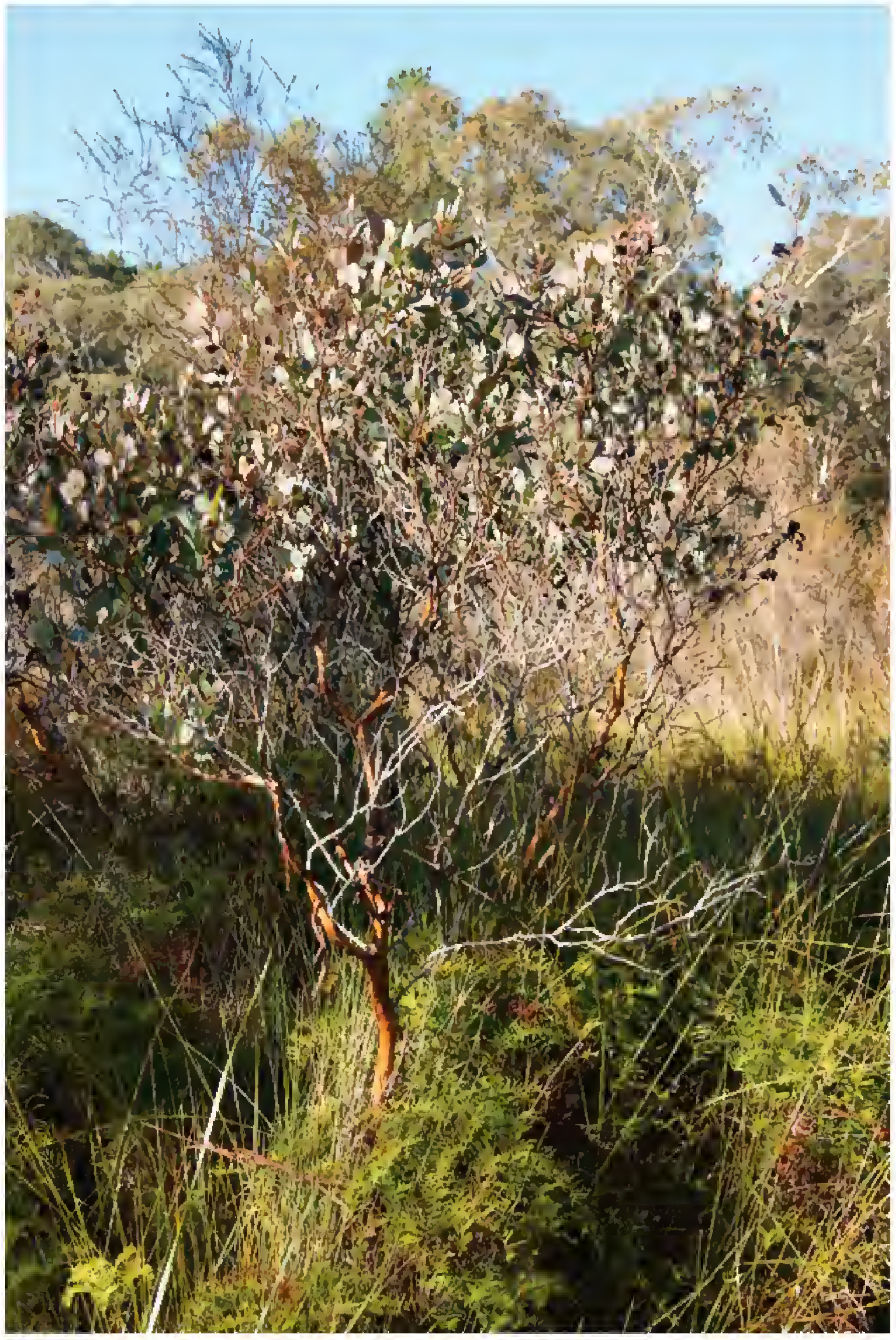

Fig. 5. View of the swamp showing *Eucalyptus aquatica* and associated plants (Flora Reserve, Penrose State Forest).

Below a hard conglomerate bed, there are overhangs above the swamp, indicating a weaker, possibly claystone bed and there is a small waterfall 0.75 m high, on this conglomerate bed. The valley cross section below the waterfall defines a gorge section of the watercourse and the waterfall is a primary knick point (Traverse 3 in Figure 2). Downstream in the swamp at Traverse 3, the valley is still in the form of an incised gorge with steep sides, but it widens out towards the bottom of the swamp (Figure 3). In contrast upstream of Webbers Road along Traverse 2, the valley is much wider with relatively gentle side slopes (Figure 1).

At the bottom of the swamp the watercourse turns abruptly 90° into a southerly direction. At this location, shown in the long section (Figure 3), fluvial sand forms a barrier across to Paddys River. This feature is reminiscent of a flood plain levee type deposit and may indicate an older and elevated river channel (abandoned channel accretion) (Nanson & Croke, 1992; see also Brierley & Fryirs, 2005, Figure 4.6d). The swamp watercourse has been diverted by the levees and enters Paddys River downstream where the levee peters out above a river knick point.

Nature of peat deposits

The swamp occupies the organic-rich sediments of the drainage line and the accumulating materials represent peat (or organosol – Nat. Comm. on Soil and Terrain, 2009) of variable thickness above a basal sandy horizon on top of the Hawkesbury Sandstone bedrock. The top 200 mm of peat was sampled (5 tests) and found to have a pH of 6.0–6.5 , characteristic of the more alkaline nature of a swamp (Mactaggart et al., 2008; Keith 2004 p.210). Below the waterfall knick point the peat reaches a maximum thickness of 4.2 m (Figure 4), thinning rapidly downstream to <2 m and then tapering off towards the bottom of the swamp in a wedge-shaped profile (Figure 3). Between probe holes P19 to P22 there is a sandy deposit in the upper peat layers. A typical section in the thinner peat is shown in the inset of Figure 3. In most places there is 200–300 mm of fibric (fibrous) peat directly underneath the vegetation and this is underlain by hemic (semi-fibrous) and sapric (humified) peats (Nat. Comm. on Soil and Terrain, 2009). The latter is dark brown to black in colour and very wet. At the bottom of the swamp next to hole P24 the peat appears to overlay the sandy Paddys River fluvial deposits.

The thickest peat below the waterfall appears to be infilling a plunge pool cut, suggesting that the stream had much greater down cutting power in the past (Figure 3). On the valley sides above the peat there are thin sandy loams up to 750 mm thick covering the bedrock.

Swamp vegetation

Eucalyptus aquatica trees grow in association with sedge and shrub plants, mainly the tussock sedge *Gymnoschoenus sphaerocephalus* (Button grass) with *Gleichenia dicarpa* (Pouched coral fern) and two species of *Leptospermum*, *Leptospermum juniperinum* (Prickly tea tree) and *Leptospermum obovatum* (Blunt leafed tea tree). The sedge and coral fern combine to form dense high mats of vegetation up to 1.6 m, under the *Eucalyptus aquatica* trees (Figure 5). *Sphagnum* is also present in the swamp in the wettest areas, but generally limited in extent (in accord with the findings of Whinam and Chilcott, 2002). The overall health of *Eucalyptus aquatica* surveyed was good, with significant numbers of juveniles recorded (Appendix 1). However although *Eucalyptus aquatica* has been noted flowering (in January) and forming fruit, no small seedlings have been sighted, possibly due to the thick ground layer inhibiting recruitment.

Eucalyptus aquatica distribution

Dense clumps of *Eucalyptus aquatica* occur in wet deep peat below the waterfall, spanning the full gorge width (Figure 6). Clumps of up to 10 trees grow continuously along the main watercourse down to the bottom of the swamp to a point where the wet peat conditions appear to peter out. From the

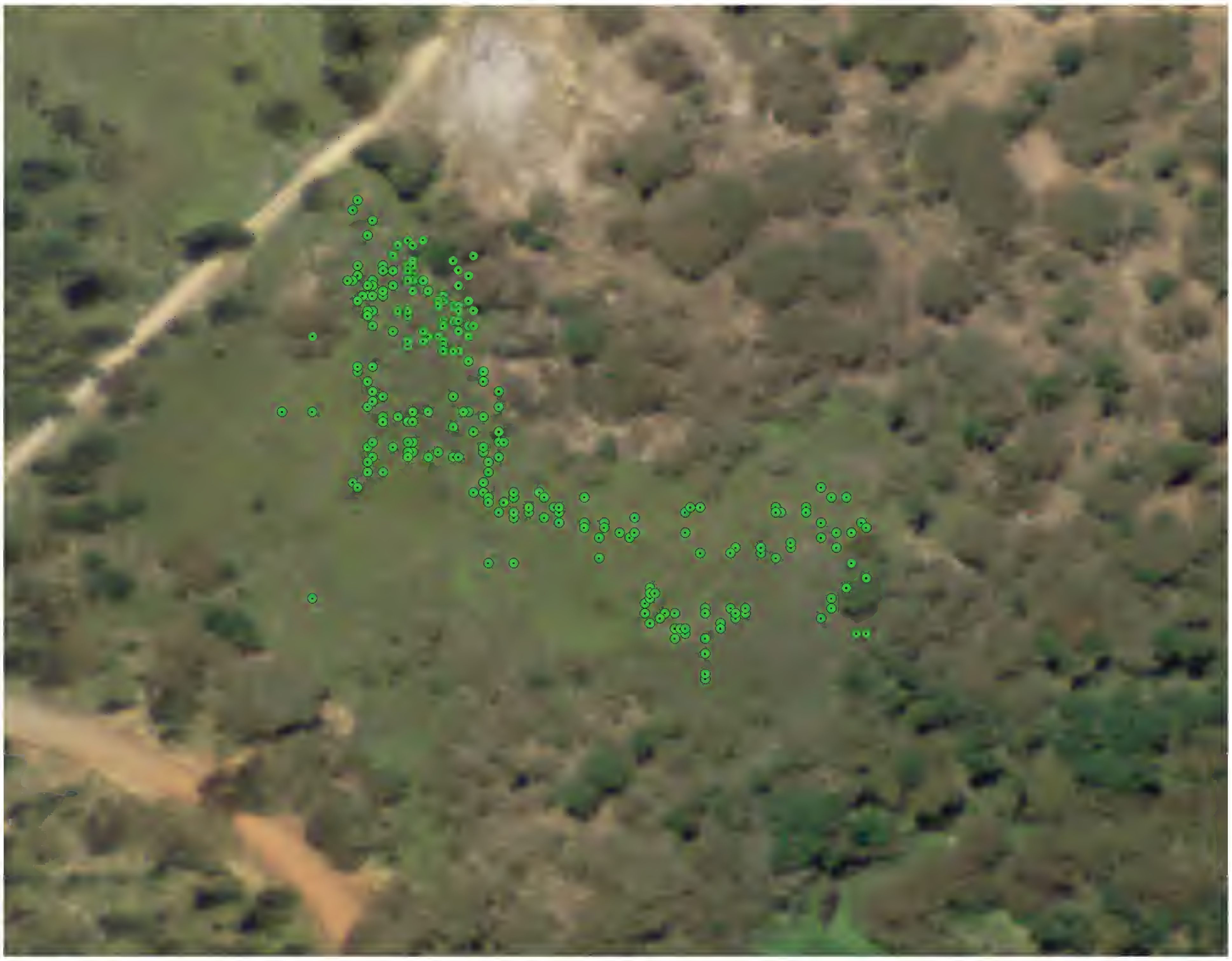

Fig. 6. Distribution of *Eucalyptus aquatica* in the swamp study area in August 2012 (Flora Reserve, Penrose State Forest).

population of 350 trees, only 34 have mallee multistems visible through the ground layer.

On the southwestern edge of the swamp there are two clumps of *Eucalyptus aquatica* growing on sandstone ledges approximately 3 m higher than the current swamp peat level (Figure 6). These clumps contain up to 10 closely spaced trees, some only 1–1.5 m apart including several larger trees with heights of 4–6 m. Using the peat probe, it was found that these trees are growing in only 300–350 mm of sandy loam (not peat), directly on the bedrock (Figure 2). It is possible that these trees once occurred in peat that has now eroded away. Several isolated and elevated trees also occur in thin sandy peat less than 750 mm thick. There is a possibility that these clumps of trees are linked in the organosol by lignotubers as has been described for some Eucalypt species (Boland et al. 1984). Recent mapping in another nearby swamp (also perched above Paddys River) shows some denuded peat with clear lignotubers (12–40 mm in diameter) connecting trees 1–2 m apart.

The height range for the majority of *Eucalyptus aquatica* trees is 2–5 m (details of individual trees are in Appendix 1). This range of heights and the presence of young trees at <1.5 m indicates that the population is currently stable (Figure 7). Common stem diameters are in the range 30–75 mm; the largest recorded is 190 mm. Stems are round and sinuous with abundant strips of loose bark present. Fruit and seed are present but we have not carried out any germination trials (a voucher specimen with fruit attached collected by us from Stingray Swamp in 2011 has been retained at the National Herbarium of NSW).

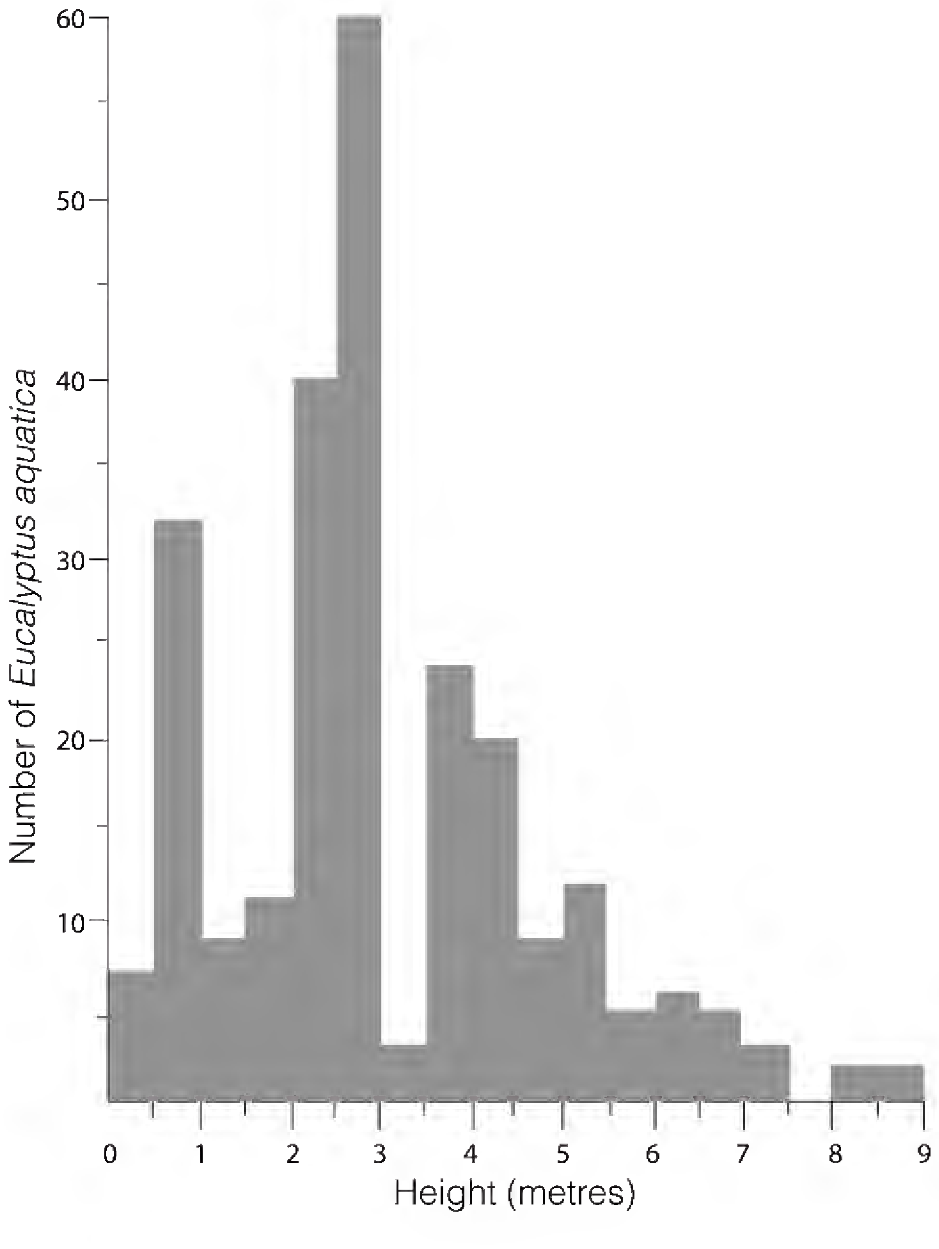

Fig. 7. Histogram of tree heights of *Eucalyptus aquatica* population (n=350) swamp study area (Flora Reserve, Penrose State Forest).

Tree condition, estimated visually based on percentage canopy alive, revealed that the majority of trees were in good condition (44%) or moderate condition (30%) ; 24% were in poor condition and 2% of trees were dead (Appendix 1).

The altitudinal range of the *Eucalyptus aquatica* population measured was very limited; all individuals occurred between 600–609 m above sea level only. *Eucalyptus aquatica* trees have been recorded at elevations up to 625 m in nearby Stingray Swamp. The limited elevation range overall is due to the limited occurrence of its particular swamp habitats and their related landscape position.

Discussion

The natural habitat of *Eucalyptus aquatica* does not appear to depend only on peat deposits as trees were also found to be occurring in sandy loam. However, it may be that the trees occurring in sandy loam originally occurred in peat that has since eroded. Water and water flow may be the critical factors that define the current occurrence of *Eucalyptus aquatica*; this hypothesis could be tested with further hydrological study. The shelter provided by the confined valley may also be a key factor in the population's current distribution.

In our particular swamp, the *Eucalyptus aquatica* population has a clumped distribution, although we could not find any visual evidence of lignotubers. Other factors may be influencing this clumping habit, again possibly associated with moisture characteristics at the site, or local conditions at the time of seedling recruitment. Recent mapping in another swamp (also perched above Paddys River) has shown *Eucalyptus aquatica* trees with lignotubers.

The longevity of the trees is unknown but the population of *Eucalyptus aquatica* appears stable and in good health. Although current texts state that *Eucalyptus aquatica* is a tree to 7 m, trees mapped in this study were as tall as 9 m. How the species has responded to fire, particularly with respect to the last two major bushfires, reported by Forestry Corporation of NSW to have occurred in 1939 and 1965, is unknown.

This study raises numerous research questions regarding the occurrence of *Eucalyptus aquatica* in montane swamps. For example, is the present localised population a relic from past colder, wetter climates? It is also possible that the clumps of *Eucalyptus aquatic* presently located adjacent to, but not in, the swamp represent a previously larger extent of swamp, and together with the suggested prior plunge pool, implies past climatic variability.

Eucalyptus aquatica has also been identified at Hanging Rock Swamp, Stingray Swamp and a number of unnamed swamps on the valley sides of Paddys River within and around Penrose State Forest, but it is difficult to determine the importance of our population of 350 trees in regards to the total population of the species overall due to a lack of data from other sites. Polygon mapping and numerical estimates of trees suggest a population of 750–1000 mature trees in Stingray Swamp. Mapping is also underway in additional areas to identify the extent of several smaller occurrences. This should provide an estimate of the total population of trees on which to base conservation assessment and prioritise particular conservation actions.

Conservation & Management

Scant knowledge of the ecology of many threatened species hinders our efforts to protect and manage them. *Eucalyptus aquatica* appears to have a naturally restricted range and limited available habitat and for the species' continued survival the protection and management of the associated swamp and swamp habitat is necessary. Appropriate management recommendations include:

An effective buffer zone should be placed around these swamps to protect them from forestry actions. Smith & Smith (2010) suggest a buffer of 60 m to protect significant native vegetation in the Blue Mountains region and this could be used as a guide for the Penrose Swamps;

Management should consider factors that might impinge on the current hydrology of these sites and this might include rerouting of existing vehicle tracks e.g. between the existing swamp crossing and Penrose Forest Way (Webbers Rd); as well as restricting public access to minimise impacts from four-wheel driving and rubbish dumping;

Management should also consider the installation of relevant signage highlighting the importance of the high conservation value of the swamps and the possible penalties applicable if damage should occur;

The upper portion of this swamp system has degraded, and contains dense stands of *Pinus radiata* wildings requiring active management and potentially the re-planting of native species. The establishment of *Pinus radiata* in the swamp could have negative effects through shading and competition on native species and on the hydrology, and hence persistence of *Eucalyptus aquatica* at this site.

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Appendix 1. Location, elevation, tree height and tree condition data for individual *Eucalyptus aquatica* trees mapped within the Paddys River swamp study site (Flora Reserve, Penrose State Forest).

Mapped in August 2012 using Google earth imagery (dated 24/10/2009) and a Garmin hand-held GPS to measure tree locations and a Suunto altimeter to measure elevations. Tree height estimated in metres; where trees are mapped in clusters the maximum height is recorded. Tree condition was estimated visually based on percentage of tree canopy alive: dead (0), poor (1–40%), moderate (41–75%), good (>75%).

Tree site #	No. of trees	Latitude	Longitude	Elevation(m)	Tree H(m)	Tree condition assessment
1	1	-34.65560	150.21811	606	6.5	poor
2	1	-34.65558	150.21812	606	3.5	moderate, top 1.5m dead
3	8	-34.65562	150.21815	605	7	moderate, dead in tops, live at half height
4	2	-34.65565	150.21814	604	6	good
5	1	-34.65567	150.21820	602	3	moderate, reshooting at half height
6	1	-34.65566	150.21822	603	3	poor, leaning over
7	1	-34.65569	150.21819	603	3.5	good
8	1	-34.65567	150.21823	603	3.5	poor, almost dead, next to a pine
9	1	-34.65570	150.21823	604	4	poor, green top only
10	1	-34.65571	150.21822	604	3	poor, green top only
11	1	-34.65571	150.21823	604	3	poor, green top only
12	1	-34.65573	150.21823	604	3	poor, green top only
13	1	-34.65571	150.21823	604	2.5	poor, green top only
14	1	-34.65572	150.21822	604	2.5	poor, green top only
15	1	-34.65574	150.21823	604	4	poor, green top only
16	1	-34.65576	150.21826	604	4.5	good
17	1	-34.65576	150.21823	604	5	moderate
18	1	-34.65572	150.21819	604	3.5	good
19	1	-34.65571	150.21817	604	3	good
20	1	-34.65574	150.21815	604	3	good
21	1	-34.65572	150.21817	604	4	moderate, green foliage to half height
22	1	-34.65575	150.21815	604	2	good
23	1	-34.65577	150.21817	604	4	good
24	1	-34.65576	150.21817	604	2	moderate,re-growing with a dead top
25	1	-34.65577	150.21814	604	3	good
26	1	-34.65577	150.21813	604	2.5	good
27	1	-34.65571	150.21812	605	4	moderate
28	1	-34.65573	150.21812	605	3	moderate
29	1	-34.65574	150.21811	605	3	dead
30	1	-34.65575	150.21814	605	5.5	moderate
31	1	-34.65574	150.21810	605	6.5	moderate
32	4	-34.65578	150.21812	604	5	moderate
33	1	-34.65577	150.21815	604	2.5	good
34	1	-34.65580	150.21815	604	3.5	good
35	1	-34.65583	150.21815	604	3	good
36	1	-34.65580	150.21814	604	3.3	good, but a dead top
37	1	-34.65581	150.21814	604	2	good
38	1	-34.65584	150.21819	605	4	moderate
39	1	-34.65580	150.21820	605	4	good
40	1	-34.65581	150.21822	606	2	good
41	1	-34.65580	150.21822	606	4.5	moderate
42	1	-34.65575	150.21819	606	2	dead
43	1	-34.65574	150.21822	606	3	moderate
44	1	-34.65574	150.21825	607	4.5	moderate
45	1	-34.65577	150.21829	607	1	good
46	1	-34.65576	150.21826	607	2	moderate
47	1	-34.65578	150.21829	607	3	poor
48	1	-34.65578	150.21828	607	2	poor, new growth from dead trunk
49	1	-34.65579	150.21831	605	1.2	good
50	1	-34.65582	150.21831	605	2	good

Tree site #	**No. of trees**	**Latitude**	**Longitude**	**Elevation(m)**	**Tree H(m)**	**Tree condition assessment**
51	1	-34.65582	150.21831	605	2	moderate
52	1	-34.65579	150.21832	605	2.5	good
53	6	-34.65582	150.21829	606	2.5	good
54	1	-34.65584	150.21832	606	4	good
55	1	-34.65583	150.21829	606	6	good
56	1	-34.65585	150.21828	606	5	moderate
57	1	-34.65585	150.21828	606	2	good
58	1	-34.65585	150.21803	606	3	good
59	1	-34.65585	150.21826	606	3	good
60	1	-34.65586	150.21825	606	6.5	moderate
61	1	-34.65584	150.21825	606	6.5	good
62	2	-34.65587	150.21822	606	0.75	good
63	1	-34.65586	150.21822	606	3	good
64	1	-34.65592	150.21812	606	3.5	poor, but new green shoots
65	1	-34.65591	150.21812	605	1	good
66	1	-34.65591	150.21815	606	2.2	moderate, dead in top
67	1	-34.65594	150.21814	606	1.8	moderate, young tree dead in top
68	1	-34.65596	150.21815	606	3	good
69	4	-34.65601	150.21817	606	4	moderate, brown growths
70	2	-34.65599	150.21814	607	2.2	good
71	1	-34.65598	150.21815	607	3.5	moderate, brown growths
72	1	-34.65597	150.21817	607	4	poor, brown growths
73	1	-34.65602	150.21817	607	5	good, leaning at 45 deg
74	2	-34.65601	150.21820	607	1	good
75	1	-34.65602	150.21822	607	1.5	good, young tree
76	1	-34.65602	150.21823	607	2.75	poor ,green top, brown growths
77	1	-34.65600	150.21823	607	5	poor ,green top, brown growths
78	1	-34.65600	150.21826	609	2.2	poor ,green top, brown growths
79	6	-34.65603	150.21831	609	5	poor ,green top, brown growths
80	3	-34.65608	150.21828	609	3	good
81	1	-34.65609	150.21831	609	5	moderate, brown growths
82	1	-34.65609	150.21832	609	2.5	poor
83	2	-34.65609	150.21826	609	3.5	good
84	1	-34.65606	150.21823	609	2.5	good
85	1	-34.65606	150.21822	609	1.75	good
86	1	-34.65608	150.21823	608	1.1	good, young tree
87	2	-34.65607	150.21819	608	1.1	good, young tree
88	1	-34.65609	150.21815	608	2	good, young tree
89	1	-34.65607	150.21814	607	3.5	moderate
90	1	-34.65606	150.21815	608	3.5	good
91	1	-34.65610	150.21814	609	2.5	moderate
92	2	-34.65608	150.21822	608	1.5	good, young trees
93	2	-34.65609	150.21822	608	1	good, young trees
94	1	-34.65612	150.21817	608	3.5	good, young trees
95	1	-34.65612	150.21814	608	6	good, minor dead branches
96	1	-34.65614	150.21811	608	6	good, minor dead branches
97	1	-34.65615	150.21812	608	8	moderate
98	1	-34.65600	150.21803	609	3.5	good, some brown growths
99	2	-34.65600	150.21797	609	4	moderate, but new shoots
100	1	-34.65566	150.21825	603	4.5	poor
101	1	-34.65570	150.21831	604	3.5	good
102	1	-34.65569	150.21835	605	4	moderate, green at half height, dead top
103	1	-34.65572	150.21832	605	4.5	poor
104	1	-34.65573	150.21834	605	2.1	good
105	1	-34.65575	150.21832	606	3.5	poor, green shoots at 1.2m height
106	2	-34.65578	150.21834	606	2.25	moderate
107	3	-34.65580	150.21832	606	1.2	good
108	4	-34.65579	150.21828	606	1.3	good
109	1	-34.65582	150.21832	606	5.5	good
110	1	-34.65580	150.21835	606	3	good

Tree site #	No. of trees	Latitude	Longitude	Elevation(m)	Tree H(m)	Tree condition assessment
111	1	-34.65583	150.21834	605	4	good
112	2	-34.65583	150.21835	605	4.5	moderate
113	2	-34.65585	150.21834	605	3	poor, green reshooting at half height
114	1	-34.65588	150.21832	605	4.5	good
115	1	-34.65588	150.21831	605	4.5	good
116	1	-34.65586	150.21829	605	2.5	moderate
117	1	-34.65587	150.21829	605	2	good
118	1	-34.65588	150.21829	606	2	good
119	1	-34.65588	150.21832	606	5	good ,some brown growths
120	1	-34.65588	150.21831	606	4	dead and brown growths
121	10	-34.65590	150.21834	606	4	moderate, brown growths
122	1	-34.65592	150.21837	604	1.8	good
123	1	-34.65599	150.21840	605	3	poor, dead top, brown growths, shoots half height
124	1	-34.65592	150.21837	606	1.7	dead
125	1	-34.65597	150.21831	606	1.7	moderate, brown growths
126	1	-34.65596	150.21840	604	4	good
127	1	-34.65594	150.21837	604	1	good
128	1	-34.65600	150.21834	604	2.1	good
129	1	-34.65600	150.21833	604	4	dead
130	3	-34.65608	150.21837	604	5	moderate, brown growths
131	1	-34.65604	150.21835	604	3	good
132	1	-34.65601	150.21837	604	3.5	moderate
133	2	-34.65607	150.21837	604	5	good
134	1	-34.65604	150.21840	604	3.5	moderate
135	1	-34.65606	150.21840	605	3.25	poor
136	6	-34.65609	150.21840	605	4.5	good, trees 1m apart
137	2	-34.65606	150.21841	604	3	poor, dead top reshooting at half height
138	1	-34.65610	150.21838	603	3.5	poor, reshooting, brown clusters
139	2	-34.65612	150.21838	603	3	poor, leaning, reshooting, brown growths
140	1	-34.65614	150.21837	602	2.5	poor, reshooting
141	1	-34.65616	150.21835	602	3.5	good
142	1	-34.65616	150.21837	602	1	good, young tree
143	1	-34.65617	150.21838	602	2.5	dead
144	1	-34.65618	150.21838	602	2.5	poor
145	1	-34.65616	150.21835	601	2.5	moderate
146	1	-34.65617	150.21843	602	1	good, young tree
147	1	-34.65618	150.21841	602	1.2	good, young tree
148	1	-34.65620	150.21840	602	1	good, young tree
149	1	-34.65621	150.21843	602	1.2	good, young tree
150	1	-34.65616	150.21843	602	3	poor, brown growths
151	1	-34.65620	150.21843	602	0.75	good, young tree, 100% good green foliage
152	1	-34.65620	150.21846	602	2.75	good
153	6	-34.65616	150.21848	603	4	poor, brown growths
154	4	-34.65619	150.21846	602	3.25	good
155	1	-34.65630	150.21838	603	1.2	moderate, dead top, reshooting at half height
156	1	-34.65630	150.21843	601	1.5	good
157	1	-34.65621	150.21849	601	3	good
158	3	-34.65617	150.21849	601	2.5	moderate
159	1	-34.65619	150.21851	601	0.75	good, young tree
160	2	-34.65620	150.21852	601	2.2	moderate
161	1	-34.65622	150.21852	601	2	good
162	2	-34.65619	150.21852	601	2	poor, almost dead, reshooting at half height
163	1	-34.65622	150.21857	600	3	good
164	1	-34.65623	150.21861	600	1.2	good
165	1	-34.65617	150.21857	600	3.5	poor, reshooting
166	1	-34.65622	150.21861	601	3.5	poor, reshooting, brown growths
167	3	-34.65623	150.21861	601	1.75	good
168	1	-34.65623	150.21857	601	1.2	good
169	2	-34.65625	150.21860	601	1.2	good
170	1	-34.65629	150.21860	601	1.1	good

Tree site #	**No. of trees**	**Latitude**	**Longitude**	**Elevation(m)**	**Tree H(m)**	**Tree condition assessment**
171	1	-34.65624	150.21864	601	1.1	good
172	1	-34.65625	150.21866	601	1.5	good
173	1	-34.65624	150.21867	601	1.5	good
174	1	-34.65621	150.21867	601	1.1	good
175	1	-34.65624	150.21877	603	2	good
176	1	-34.65620	150.21877	602	1	good
177	3	-34.65628	150.21880	602	2	moderate, brown growths
178	5	-34.65628	150.21880	602	2.5	moderate
179	1	-34.65619	150.21880	603	2.1	good
180	1	-34.65619	150.21878	603	1	good
181	1	-34.65627	150.21887	602	2	poor
182	1	-34.65628	150.21886	602	1.2	good
183	1	-34.65628	150.21892	602	1	good
184	1	-34.65629	150.21895	603	3.5	poor, reshooting
185	1	-34.65619	150.21895	603	8	moderate
186	1	-34.65625	150.21904	603	3	poor
187	1	-34.65627	150.21892	603	0.5	good
188	2	-34.65627	150.21898	603	2.3	poor, reshooting from base
189	2	-34.65626	150.21898	603	2.2	poor
190	1	-34.65620	150.21896	604	2	poor
191	1	34.65620	150.21895	604	2	moderate
192	3	-34.65619	150.21901	604	2.5	moderate
193	1	-34.65620	150.21901	604	1.8	moderate
194	1	-34.65622	150.21904	604	2	poor
195	7	-34.65615	150.21904	604	3	poor, reshooting from base
196	1	-34.65617	150.21906	604	1.5	poor
197	1	-34.65617	150.21909	604	1.1	moderate
198	1	-34.65622	150.21912	603	2.25	moderate
199	2	-34.65623	150.21913	603	2	moderate
200	1	-34.65624	150.21910	603	1.5	poor
201	1	-34.65624	150.21907	603	0.75	moderate
202	1	-34.65627	150.21907	602	4	moderate and brown growths
203	1	-34.65630	150.21910	604	2.5	poor
204	1	-34.65633	150.21913	604	2.5	poor
205	1	-34.65635	150.21909	604	1.5	good
206	1	-34.65637	150.21803	604	5	good
207	1	-34.65639	150.21886	604	0.5	good, young tree
208	1	-34.65640	150.21889	604	1.8	good
209	1	-34.65639	150.21881	603	3	good
210	1	-34.65641	150.21887	603	2.3	good
211	1	-34.65639	150.21889	604	1.6	good
212	1	-34.65640	150.21887	604	3.5	poor, reshooting
213	2	-34.65640	150.21881	604	4	moderate
214	1	-34.65642	150.21884	603	9	poor
215	2	-34.65643	150.21884	603	5.5	poor
216	1	-34.65653	150.21881	603	3.5	poor
217	1	-34.65652	150.21881	604	4	poor
218	2	-34.65648	150.21881	605	3	poor
219	1	- 34.65643	150.21878	605	2.75	moderate
220	2	-34.65645	150.21881	605	2.75	moderate
221	1	-34.65644	150.21877	605	2.5	good
222	1	-34.65643	150.21875	606	2	good
223	1	-34.65645	150.21875	606	1	good, young tree
224	1	-34.65643	150.21876	606	1	good, young tree
225	5	-34.65643	150.21877	606	1.2	good, young tree
226	1	-34.65640	150.21875	606	2	good
227	1	-34.65640	150.21873	606	4	moderate
228	2	-34.65641	150.21872	606	3	poor, reshooting
229	1	-34.65642	150.21870	606	1.5	good
230	4	-34.65640	150.21869	606	2	poor, reshooting

Tree site #	No. of trees	Latitude	Longitude	Elevation(m)	Tree H(m)	Tree condition assessment
231	2	-34.65638	150.21869	606	1	good, young tree
232	1	-34.65637	150.21870	606	6	poor, brown growths
233	1	-34.65635	150.21870	606	0.75	good, young tree
234	1	-34.65636	150.21870	606	1.2	dead
235	1	-34.65636	150.21871	606	4	good
236	3	-34.65637	150.21906	603	3	moderate
237	2	-34.65639	150.21906	603	7	moderate
238	1	-34.65644	150.21913	602	5.5	moderate
239	2	-34.65644	150.21911	602	3	moderate, reshooting
240	1	-34.65641	150.21904	602	9	poor

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The contribution of vegetation survey and mapping to Herbarium collections and botanical knowledge: a case study from Queensland.

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***Abstract*:** The Queensland Herbarium Regional Ecosystem Survey and Mapping (QHRESM) program has contributed almost 90000 (89389) specimens to the Queensland Herbarium in Brisbane accounting for 28% of the specimens added to the Herbarium between 1970 and 2011. These specimens have been collected across all bioregions and vegetation communities in Queensland in a systematic sampling program driven by the requirement to sample comprehensively all vegetation communities. The QHRESM's Queensland Herbarium (BRI) specimens represent more than 79% of the native, and 73% of the naturalised vascular flora of Queensland, as well as making valuable contributions to the bryophytes, lichens and liverworts collections. The data and specimens collected enhance our ability to assess local, state and continental-scale plant diversity, and will be used by botanists, ecologists, governments, business and the public for long into the future.

Key words: conservation status, floristic composition, Herbarium specimens, modelling of species, Queensland flora, systematic sampling, regional ecosystems, survey and mapping, vegetation

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Introduction

Since the late 1940s Australian vegetation scientists have developed a wide variety of vegetation survey, classification and mapping systems (Benson 1995, Sun *et al.* 1997). Vegetation surveys may target the occurrence of certain plant species or all species present at a site, and range from surveys for individual threatened plant species or specific taxonomic groups, where only certain plants are targeted, through to comprehensive site surveys where all species are documented (Thackway *et al.* 2008).

Vegetation mapping projects vary in scope and comprehensiveness and in the type of outputs produced. For some projects vegetation maps and associated descriptions are the only products, e.g. the mapping of the vegetation of Western Australia by John Beard (1979), and the vegetation map of Fraser Island (Stanton, 1979). However, vegetation survey and mapping projects can also collect large amounts of systematic ecological data with a wide range of applications, e.g. underpinning benchmarks and technical descriptions for biodiversity offsets, evaluating distribution and conservation status for species listing under legislative provisions, identifying species-rich areas for conservation planning and acquisition, as well as for basic scientific studies in plant systematics and ecology.

Queensland has a diverse range of landscapes, vegetation and ecosystems in its extensive 1,730,000 km^2 area. Queensland vegetation ranges structurally from rainforests in the Wet

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Tropics bioregion to sparse-forblands and open-hummock grasslands in the Channel Country bioregion (Sattler and Williams 1999). The development of a systematic and efficient method of mapping and surveying Queensland's diverse regional ecosystems has been refined over a number of years (Neldner *et al.* 2012, Neldner and Butler 2008). However, from the outset, the Queensland Herbarium Regional Ecosystem Survey and Mapping program (QHRESM) program has always been seen as an opportunity to obtain a comprehensive and systematic survey of the vegetation of Queensland, providing detailed floristic and structural data that can be used for a number of purposes as described above. The minimum field data required for ground truthing for mapping purposes is limited to the ecologically dominant layer, for example in wooded communities the tree layer (Neldner and Howitt 1991). The detailed vegetation site data form CORVEG, (the Queensland Herbarium ecological site database, which currently includes data from 12,502 validated and 7,075 unvalidated sites (Neldner *et al.* 2012). Collecting to improve knowledge of the distribution of Queensland's plants and vouchering specimens to confirm plant identities (all threatened plants and any new records for a 1:100 000 map sheet) has also been part of the methodology and has contributed a large number of specimens to the Queensland Herbarium.

In this paper, the contribution of the QHRESM program to knowledge of the Queensland flora through the provision of botanical specimens is examined. The QHRESM program includes all projects since 1970 that result in the production of a vegetation or regional ecosystem paper map or digital map coverage at a variety of scales (eg. 1:25 000 coastal mapping through to 1:1 000 000 scale western region mapping), and frequently with a report describing the map legend and vegetation units. The program also includes surveys of particular restricted vegetation types, such as groundwater springs (Fensham and Fairfax 2000), semi-evergreen vine thickets (Fensham 1995) and Astrebla grasslands (Fensham *et al.* 2000) that did not necessarily produce a final vegetation map of all communities.

History of Queensland Herbarium Regional Ecosystem Survey and Mapping (QHRESM)

Botanists from the Queensland Herbarium provided ecological input into the multi-disciplinary CSIRO Land Research Series and Western Arid Region Land Use Study (WARLUS) in Queensland in the 1960–1970s. A vegetation mapping program for Queensland was devised and implemented with the assistance of Commonwealth funds through the Australian Biological Resources Study in the late 1970s (Neldner 1993a).

From 1970 to 1979, the Queensland vegetation mapping program was predominantly involved in the WARLUS (1:1 M scale), coastal mapping for the Beach Protection Authority (1:25 000), and the Moreton Region Vegetation Map Series (1:100 000). In the period of 1980 to 1994, large areas of western Queensland were mapped through the Vegetation Survey of Queensland (1:1 M), together with the Cape York Peninsula Land Use Study (1:100 000), Mackay coast mapping (1:25 000), Darling Downs mapping, Desert Uplands bioregion mapping and continued Southeast Queensland mapping. From 1995 to 1997, there was an active period of mapping in Southeast Queensland under the Forest Agreement process (McAlpine *et al.* 2005), together with the commencement of regional ecosystem (see Sattler and Williams 1999) mapping in the Brigalow Belt, Einasleigh Uplands and Bartle Frère 1:100 000 map sheet of the Wet Tropics, and surveys of the Mitchell grass, artesian springs and serpentine areas of Queensland. In the final period since 1998, regional ecosystem mapping program activity has concentrated on the eastern bioregions and through the Gulf Plains and Northwest Highlands bioregions.

Forty-three years since its commencement, the mapping of Queensland's vegetation and regional ecosystems is 95% completed at 1:100 000 or larger scale, and 1386 regional ecosystems have been defined and mapped (Queensland Government 2012). The coverage of regional ecosystems across both pre-cleared environments and remnant vegetation is readily available on the Queensland Government data website (https://data.qld.gov.au/) and has been used increasingly by government, business, landholders and the community for a wide variety of planning (e.g. biodiversity planning assessments for bioregions), regulatory (eg. tree clearing under the Vegetation Management Act 1999), fire hazard risk assessment, and educational uses.

Methods

The Queensland Herbarium (International Herbarium acronym BRI, ie. short for Brisbane) was one of the first herbaria in Australia to document its specimens in a database, HERBRECS (Johnson 1991). HERBRECS is a corporate Oracle database consisting of 826,374 specimen records (on 7th November 2013). HERBRECS was interrogated on the basis of the primary specimen collector to find those specimens collected during survey and mapping projects in Queensland in the last 43 years. Most of the selected collectors were primarily involved in survey and mapping projects on a full time basis; all specimens collected by them could be attributed to this activity. However, some collectors were involved in a number of different projects or submitted specimens collected in a private capacity. These collections were excluded with the aid of ArcGIS mapping software to identify collections not associated with the program. The author, who was part of the QHRESM program from 1980 and managed the program from 1996 to 2004, used his knowledge of the collectors and their projects to refine the selected list down to those attributable to survey and mapping projects. Once the specimens that were attributed to survey and mapping activities were distinguished, they were analysed by criteria including taxonomic family, genera, date of collection, conservation status and native status. The data manipulation, statistical summarisation and graphics production were performed within the R computing environment (http://www.r-project.org/).

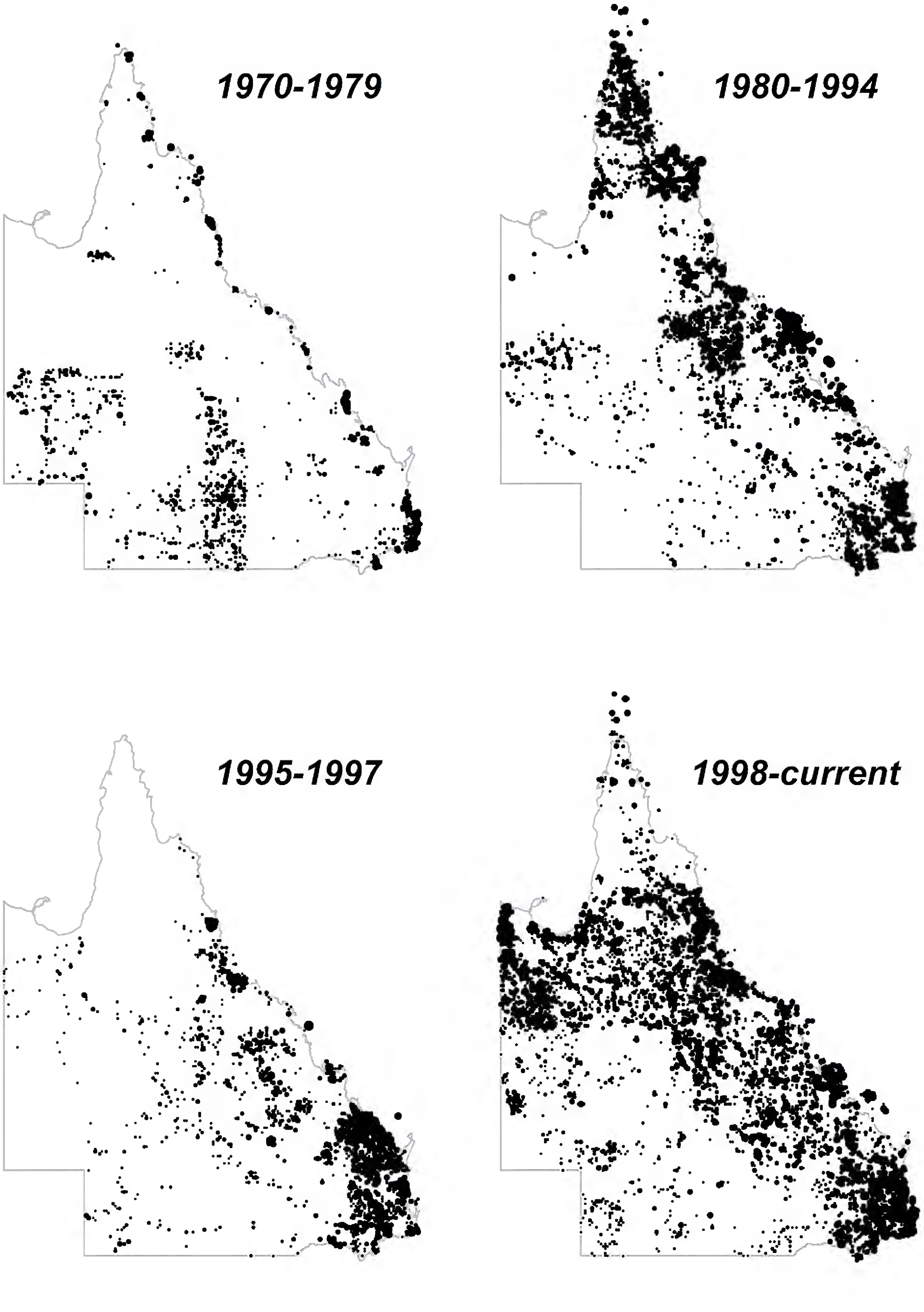

Fig. 1. Geographic distribution and density of BRI Herbarium specimens collected during significant phases of the QHRESM program.The number of specimens in each 80 km^2 grid cell (0.083 degree latitude by 0.083 degree longitude) was calculated. For each cell, the dot size is proportional to the logarithm of the specimen count.

The geographic distributions of the specimens collected during the QHRESM program were mapped on the basis of relevant periods (years collected) and the density of collections (Figure 1) using the count of specimens for each 80 km^2 grid cell (0.083 degree latitude by 0.083 degree longitude). This map illustrates the distribution and intensity of collecting of BRI specimens through the QHRESM program for various time periods.

Results

About 50 botanists and technicians involved in QHRESM projects have lodged specimens at BRI Herbarium. About 20 collectors each with more than 1000 BRI specimens from the QHRESM program are listed individually in Table 1 together with the number of specimens lodged; a combined number is given for other collectors. For all collectors, the specimens that were not collected as part of QHRESM program have been removed from the analysis.

Also listed in Table 1 are data on the conservation (E = Endangered, V = Vulnerable, NT = Near Threatened, LC = Least Concern listing under the *Nature Conservation Act 1992*) and native status of the taxa. Specimens from 369 families were collected during the program from 1970–2011, with the majority being vascular plants and least concern (LC) native species.

Table 2 lists the number of specimens collected as part of the QHRESM program listed alphabetically by family (where >1000 specimens), and other plant groups. The QHRESM BRI Herbarium collections made up 28% of the overall collections for native plants, 31% of the non-native plant collections and only 16.5% of the threatened plant specimens. For all of the largest Angiosperm families at least 20% of the specimens came from QHRESM, with higher proportions (>30%) from the Poaceae, Cyperaceae, Malvaceae and Chenopodiaceae. These families generally dominate the ground layer and frequently require identification in the laboratory. The QHRESM specimens made up a higher proportion (31%) of non-native specimens collected and a lower proportion of threatened taxa (16%).

The number of species collected by the QHRESM program is compared to the total flora for Queensland as documented by Bostock and Holland (2010) for the major plant groups in Table 3, and the largest families and genera in Table 4.

The frequency of Angiosperm taxa collected as part of QHRESM program and lodged as BRI Herbarium specimen ranges from 943 taxa represented by only a single specimen, to taxa represented by more than 100 specimens (Table 5) not included in Figure 2.

The number of specimens added to BRI by the QHRESM program from 1970 to 2011 was 89 389 specimens (28% of the total of 316 982). Figure 2 shows the number of specimens

Table 1. Primary collector and number of QHRESM specimens by Threat status, non-native and undescribed taxa status incorporated as BRI Herbarium specimens from collections made during the survey and mapping program up to December 2011. Threat status E = Endangered, V = Vulnerable, NT = Near Threatened, LC = Least Concern listing under the *Nature Conservation Act 1992*. Undescribed taxa = specimens assigned to a genus and phrase name

Primary Collector	Total	E	V	NT	LC	Non-native	Undescribed taxa
Bean A.R.	14897	94	214	159	12068	2362	117
Batianoff G.N.	12448	19	89	112	9726	2502	66
Thompson E.J.	10365	20	53	79	9506	707	270
Clarkson J.R.	5906	6	41	50	5493	316	80
Fensham R.J.	5863	53	63	48	5202	497	79
Cumming R.J.	3971	8	21	63	3469	410	55
Booth R.	3180	2	7	22	3030	119	88
Neldner V.J.	2822	0	8	15	2620	179	39
Fox I.D.	2452	1	4	10	2212	225	23
Fell D.G.	2386	2	27	65	2259	33	76
Grimshaw P.G.	2320	24	66	92	2107	31	29
Pollock A.B.	2177	4	16	15	1898	244	15
McDonald W.J.	2144	10	43	84	1943	64	27
Stephens K.M.	1930	4	7	14	1669	236	8
Kemp J.E.	1922	3	6	13	1764	136	28
Johnson D.C.	1332	0	4	1	1265	62	14
Purdie R.W.	1350	0	5	5	1306	34	22
Hunter J.T.	1284	2	22	82	1158	20	45
Turpin G.P.	1157	0	1	7	1102	47	16
Other^	9483	45	81	79	8477	801	110
TOTAL	**89389**	**297**	**778**	**1015**	**78274**	**9025**	**1207**

^Other includes the BRI collections of Addicott E.P., Appelman C.N., Bailey L., Baumgartner D.J., Beeston, G.R., Boyland, D.E., Brushe J., Butler D.W., Cartan H., Dillewaard H.A., Dowling R.M., Durrington, L., Edginton M.A., Elsol J.A., Fairfax R.J., Horton S.A., Kahler C., Kelman D.T., Lovatt R., McDonald T.J., Pennay C., Richter D., Ryan T.S., Schmeider M., Sparshott K.M., Sullivan S.C., Thompson S.L., Wilson B.A., Wilson G.W. and Young P.A.

Table 2. Number of QHRESM specimens (total 89383) listed by major plant family or taxonomic group, showing number of native, non-native and Threatened (E,V,NT) specimens and the proportional contribution to the total BRI Herbarium specimen collections (for 1970-2011).

Family	No. of native	% of total native	No. of non-native	% of total non-native	No. of E, V, or NT	% of total E, V or NT
Poaceae	11292	42.5	1733	24.5	126	26.3
Myrtaceae	6160	27.7	54	38.0	329	22.5
Cyperaceae	5380	39.4	238	32.2	35	23.0
Fabaceae	5310	28.2	823	25.0	47	20.9
Mimosaceae	3508	24.4	155	22.0	123	17.3
Asteraceae	3226	30.2	1287	24.5	107	27.9
Rubiaceae	1857	24.3	113	22.1	26	12.7
Malvaceae	1658	35.8	406	28.3	3	42.9
Sapindaceae	1543	24.5	35	24.3	50	12.6
Euphorbiaceae	1520	24.8	209	22.2	62	15.5
Rutaceae	1382	20.7	20	35.1	80	12.9
Phyllanthaceae	1374	28.1	20	20.6	30	15.7
Lamiaceae	1202	26.2	207	25.4	30	14.5
Apocynaceae	1167	21.5	234	28.7	72	21.9
Chenopodiaceae	1141	30.4	23	17.6	2	6.3
Proteaceae	1017	20.7	0	0	79	12.6
Other Angiosperms#	28782	25.7	3444	58.6	824	16.5
Gymnosperms	123	6.4	123	15.5	0	0
Pteridophyta	1819	11.2	24	5.6	27	6.4
Bryophyta	137	4.6	0	0	0	0
Lichens & Liverworts	522	3.9	0	0	38	0
Algae	47	3.5	0	0	0	0
Fungi	320	3.8	0	0	0	0
Total	**89389**	**28.2**	**9025**	**30.9**	**2090**	**16.5**

Other Angiosperms is represented by 257 families, Gymnosperms by 4 families, Pteridophytes by 34 families, Bryophytes by 17 families, Lichens and Liverworts by 40 families, Algae by 2 families, and fungi by 24 families.

Table 3. Major plant groups showing number of taxa collected by QHRESM program specimens compared to total for Queensland.

	Species identified from QHRESM program	Taxa identified from QHRESM program	QLD species (Bostock & Holland 2010)	% Qld species collected by QHRESM program	No. of BRI specimens
Native vascular	6549	6897	8449	78	77519
Naturalised alien	918	936	1258	73	9015
Angiosperms	6308	6665	8005	79	75758
Gymnosperms	41	41	62	66	121
Pteridophyta	187	190	381	49	1640
Bryophytes	25	25	555	5	43
Lichens & Liverworts	102	102	1309	8	198
Algae	10	10	1505	0.01	11
Fungi	47	47	na	na	71

Table 4. Number of taxa represented by QHRESM program specimens for selected families and genera with high species diversity, and comparison with total taxa for Queensland (Bostock & Holland 2010).

Family/genera	No of Species	No of Taxa	No of QLD species	% Qld species	No. of BRI specimens
Poaceae	550	579	629	87	11216
Myrtaceae	524	543	601	87	6202
Fabaceae	376	409	474	79	4866
Acacia + *Vachellia*	258	272	308	84	3121
Corymbia +*Eucalyptus*	212	225	222	96	3020

Table 5. Frequently recorded QHRESM program taxa with more than 100 specimens in BRI Herbarium

Taxon	**Family**	**No. of BRI specimens**	**No. of Bioregions recorded**	**No. of CORVEG records**
Fimbristylis dichotoma (L.) Vahl	Cyperaceae	177	13	800
Cyanthillium cinereum (L.) H.Rob.	Asteraceae	146	12	1395
Eucalyptus crebra F.Muell.	Myrtaceae	145	10	1670
Aristida holathera Domin var. *holathera*	Poaceae	143	13	500
Alphitonia excelsa (Fenzl) Benth.	Rhamnaceae	132	12	1892
Enneapogon lindleyanus (Domin) C.E.Hubb.	Poaceae	123	12	463
Corymbia clarksoniana (D.J.Carr & S.G.M.Carr) K.D.Hill & L.A.S.Johnson	Myrtaceae	118	11	890
Panicum effusum R.Br.	Poaceae	108	13	710
Allocasuarina littoralis (Salisb.) L.A.S.Johnson	Casuarinaceae	107	8	648
Schizachyrium fragile (R.Br.) A.Camus	Poaceae	106	13	804
Cyperus difformis L.	Cyperaceae	105	13	88
Melaleuca viridiflora Sol. ex Gaertn. var. *viridiflora*	Myrtaceae	103	9	945

collected through the program each year compared to the total specimens incorporated into the Queensland Herbarium for the same year. Specimens from the program made up only 1% of the total number added to the Herbarium in 1973,up to a maximum of 49% of the specimens incorporated in 1994.

A large number of Angiosperm taxa were only collected and lodged in BRI by the QHRESM program a few times, while there were 12 species that were represented by more than 100 specimens in BRI. The frequency of BRI collection of individual Angiosperm taxa during the QHRESM program is illustrated in Figure 3.

As a measure of the geographic distribution of the QHRESM collections, the proportion of the total Herbarium specimens that are QHRESM collections in each of the 15 Pastoral Districts that make up Queensland is shown in Figure 4. At least 15% and up to 52% of BRI specimens for every Pastoral District were collected through the QHRESM program.

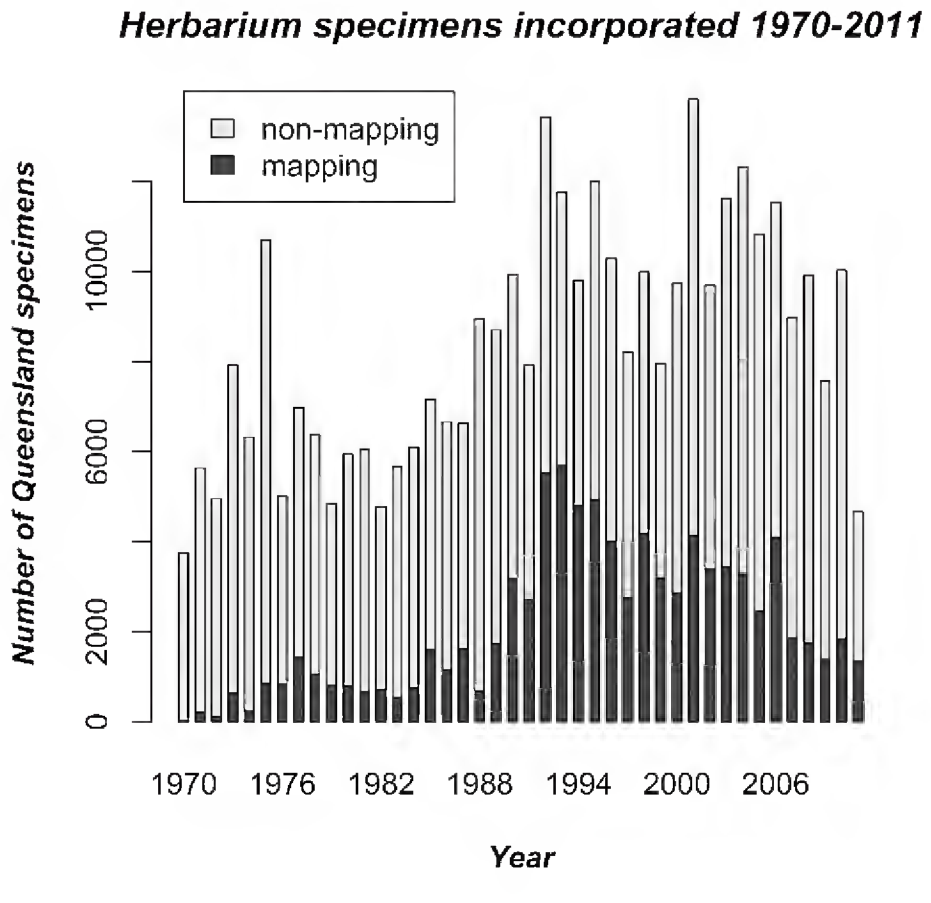

Fig. 2. Stacked bar chart of number of specimens collected through the QHRESM program by each year compared to the total specimens incorporated into BRI Herbarium for the same year.

Discussion

The results compiled above (particularly Table 1, Figure 1) demonstrate the significant contribution the QHRESM program has had in increasing the knowledge of Queensland's vascular plants through the specimens housed in BRI. Since 1970, the survey and mapping projects have contributed 28% of all specimens collected for BRI. During the years of 1992–1999, when the concentrated vegetation mapping activity was occurring under the Cape York Peninsula Land Use Study (CYPLUS) and Southeast Queensland Forest Agreement (SEQFA), more than 40% of collections were from this program. The QHRESM specimens, together with collections from the biodiscovery plant collecting project (P.I. Forster collections 1994–2003 of 13,808 specimens),

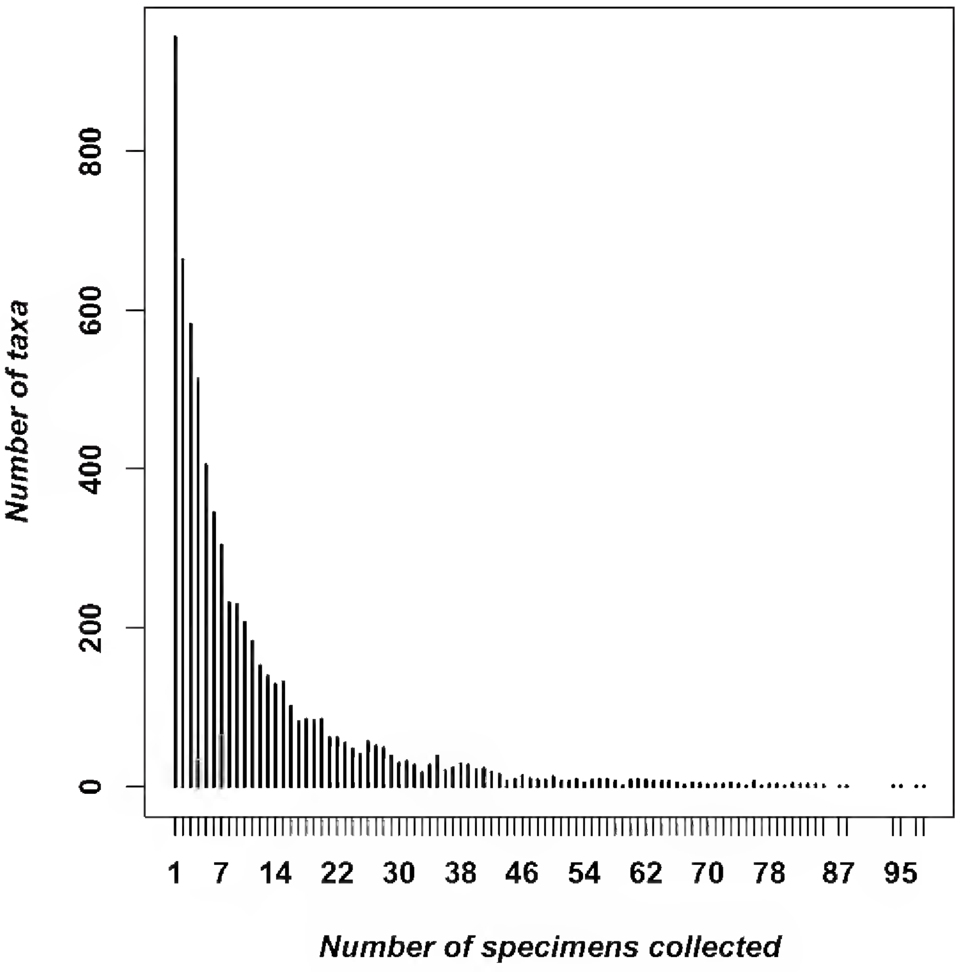

Fig. 3. Histogram of frequency of collection of individual Angiosperm taxa during the QHRESM program. 943 taxa were only collected once; 12 species collected more than 100 times are not included in this figure but are listed in Table 5.

accounted for more than 50% of accessions to the Queensland Herbarium during the 1994–2003 period. In addition to BRI specimens, duplicate specimens were also sent to other herbaria worldwide to further taxonomic study.

The QHRESM collections have provided a relatively comprehensive coverage of the overall vascular plant diversity of Queensland. For example over 77% of the described native and naturalised vascular flora has been collected (Table 3). For the largest families and genera, the QHRESM program plant collections represent more than 79% of the total Queensland flora, and for the eucalypts (*Corymbia* + *Eucalyptus*) and acacias (*Acacia* + *Vachellia*) which dominate and define the majority of wooded vegetation communities, the percentage representation is higher, greater than 83 and 95% respectively (Table 4).

The vegetation survey and mapping methodology (Neldner *et al.* 2012) requires the systematic assessment of all layers ie. tree, shrub and ground layers, and ensures that all life forms of vascular plants are inventoried. Table 2 shows a large number of families dominated by herbaceous species. While herbaceous species can frequently add a high number of overall species diversity at a site and are important for building effective surrogates for plant diversity in classification, they are not usually important for defining the vegetation community for mapping purposes, apart from in grasslands, forblands and sedgelands. The high number of herbarium specimens lodged from predominantly herbaceous dominated families indicates that botanists are recording the full vascular plant diversity at a site within the seasonal condition constraints.

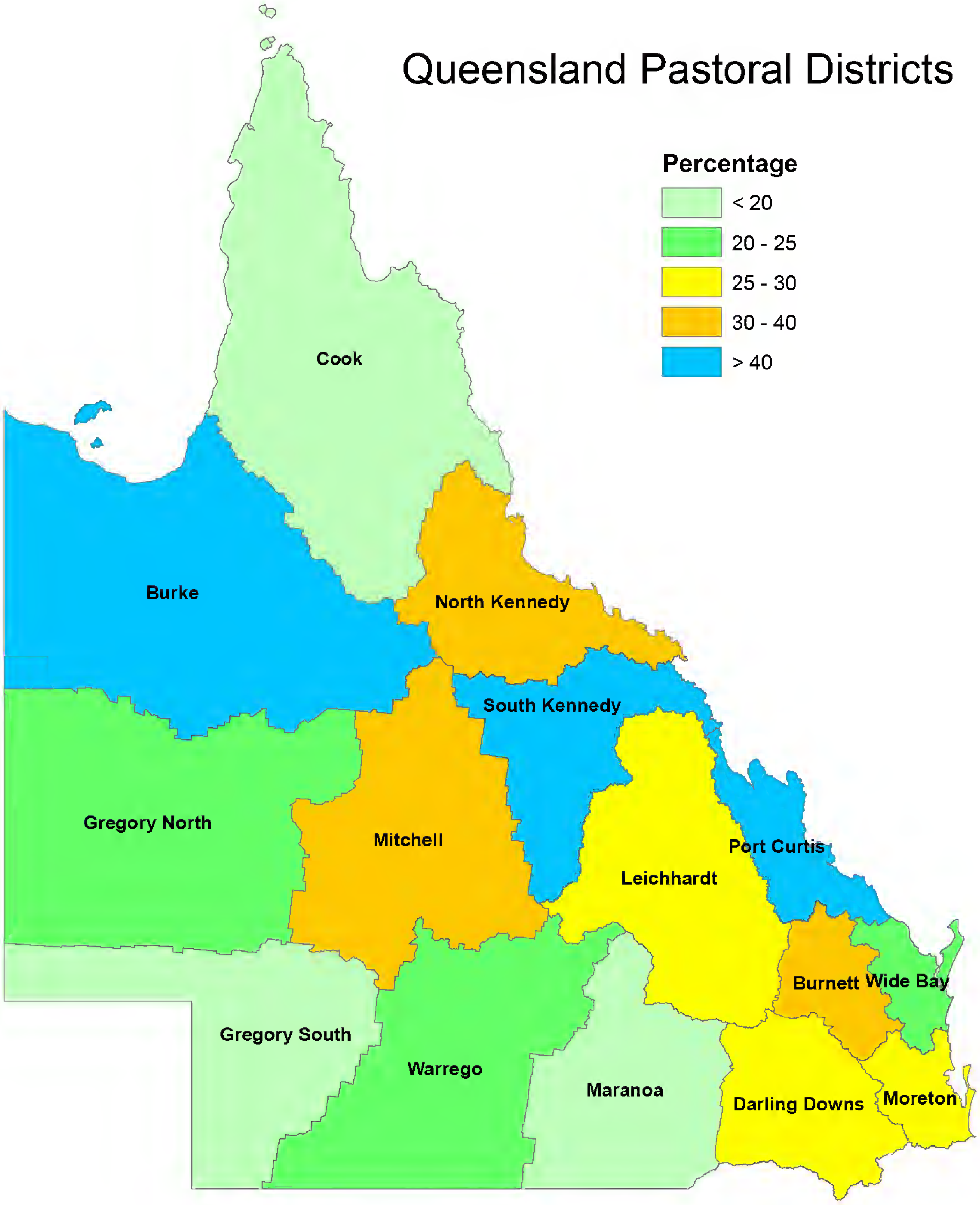

Fig. 4. Map of Queensland illustrating the proportion of BRI Herbarium collections derived from the QHRESM program in each Queensland Pastoral District.

Vascular plants dominate BRI Herbarium collections from the QHRESM program with 96% of the collections being Angiosperms, 0.15% Gymnosperms and 2.3% Pteridophytes. However while the scope of QHRESM is to describe the terrestrial vegetation, there have been significant collections of non-vascular plants: 137 mosses from 17 families, 522 lichens from 40 families, 47 Algae from 2 families, and 320 fungi from 24 families. The comprehensiveness of these non-vascular plants collections varies greatly, and is primarily driven by the interests of the individual botanist.

The QHRESM collections of the vascular flora are dominated by the Poaceae which frequently dominate the ground layer in terms of species and cover, and frequently require collecting for positive identification. Numerous collections have been made of Cyperaceae, Fabaceae, Asteraceae, Malvaceae, Euphorbiaceae, Chenopodiaceae and Phyllanthaceae which also contribute a large amount of species and cover to the ground layer. Prior to broad-scale clearing, 43% of Queensland was dominated by Eucalypt open forest and woodlands, while the semi-arid areas dominated by Acacia low woodlands and tall shrublands made up 23% of the state. By 2003 the remnant vegetation had been reduced to 33% and 16% respectively (Queensland Government 2008). Hence it is not surprising to see the numerous QHRESM collections of Myrtaceae and Mimosaceae. There are also frequent collections from families such as Myrtaceae, Rubiaceae, Sapindaceae, Rutaceae, Apocynaceae and Proteaceae that have a large number of representatives in the rainforests, which covered 1% of Queensland in 2003, about half of their pre-clearing distribution.

The QHRESM collections also reflect the plant diversity of Queensland's nearly 8500 native vascular plant species, the largest families of which are the Poaceae (629 species) Myrtaceae (601 species) and Fabaceae (474 species) (Bostock and Holland 2010) (Table 4). The 12 most frequently collected (> 100 specimens) species from the QHRESM program (Table 5) are all widely distributed and abundant species. Seven species are herbs (four Poaceae, two Cyperaceae and an Asteraceae) and occur in 12 or more of the 13 bioregions of Queensland. *Eucalyptus crebra* and *Corymbia clarksoniana* are widespread canopy trees (10 and 11 bioregions), while *Melaleuca viridiflora* (9) and *Allocasuarina littoralis* (8) can dominate the canopy or occur as subcanopy trees. *Alphitonia excelsa* (12) is usually a subcanopy tree. As well as being important for defining regional ecosystems, all of these tree species can show significant morphological variation, and these factors together with their widespread distribution explain the high BRI Herbarium specimen collection numbers.

During survey and mapping projects, many more specimens are collected than those that are eventually lodged in herbaria. Most are collected to confirm field identification and discarded once determination is resolved. Specimens of (conservation) least concern plants may be retained as vouchers or if there is no specimen for the taxa held in BRI Herbarium for the 1:100 000 map sheet area. Because of seasonal conditions at the time of surveys some specimens are infertile or of too poor quality to be lodged. Figure 2 shows that the majority of taxa are collected less than 6 times by the QHRESM program. The validated CORVEG database consists of 12,502 sites and 272,899 taxa records with average of 26 species per site. Table 5 demonstrates that generally only 15% of the CORVEG records of the 12 most collected species are vouchered. This is appropriate given the cost of collecting, identifying, processing, curating and databasing voucher specimens. The current charge by Council of Heads of Australasian Herbaria (CHAH) is $110 per hour for plant identification and $30 for specimen preparation, databasing and curation.

Herbarium specimens are fundamental to taxonomic research. While it is very difficult to provide an estimate of how many new species were discovered through the QHRESM program, the number of specimens that are only determined to genus level can give some indication of the potential numbers. Queensland Herbarium standards for accepting specimens require them to be fertile specimens (apart from some rainforest specimens) and in a state that they can be identified to species level. From the total of 89,389 BRI specimens collected by the QHRESM program, 1321 specimens could only be identified to a genus, however a further 1207 specimens (1.4%) have a generic name and phrase name (Table 1), e.g. *Acacia* sp. (Ronlow Park E.J.Thompson+ 61), and are earmarked as a potentially undescribed taxon. Bebber et al. (2010) found that only 16% of new species were described within 5 years of first being collected, while the remaining 84% were described from older specimens, some more than 50 years old. The average time lag for angiosperms was 35 years (Bebber et al. 2014). Hence many of the QHRESM BRI specimens may not be critically examined by taxonomists for many years to come. However so far at least 21 Queensland species described in the last 20 years have been given names honouring botanists involved in the QHRESM program.

Herbarium specimens have a much greater use than only plant systematics. Increasingly specimens are being used to provide genetic material to examine the systematic relationships based on genetics (Herrmann and Hummel 1994) or preserve germplasm (Lister et al. 2010), or in some cases chemical analyses are conducted to examine the phytochemistry, eg. foliar Manganese accumulation (Fernanado et al. 2009) and lead-uptake; pollution documentation; bio-prospecting (Funk 2007). Other information that can be studied from Herbarium specimens includes plant predators e.g. leaf miners, leaf-cutter ants, plant diseases eg. myrtle rust, and fungal/ vascular plant symbionts (Funk 2007).

As well as adding to the number of specimens in BRI Herbarium, the QHRESM program has greatly improved the distribution of specimens because the ecological sampling for mapping is stratified to cover all of the different vegetation types present and also to sample across the whole map area. This helps to overcome some of the problems associated with herbarium specimens worldwide which have been found to be generally clumped around specific areas (Moerman and Estabrook 2006, Feeley and Silman 2011) and biased towards species that are demographically rare in the field. Thus any estimates of species abundance based on herbarium specimens are inherently biased, and cannot be interpreted as being a predictor of their true abundance in the field (Garcillan and Ezcurra 2011). Table 2 shows that the QHRESM collections make up 28% of the total collections of native plants with a consistent rate of at least 20% of the collections across all the major Angiosperm families. However the lower rate of 16.5% for threatened plants supports the findings of a bias in general herbarium collections to demographically rare plants.

The survey and mapping methodology attempts to ensure all vegetation types are sampled based on their relative distribution in the landscape as determined from remotely sensed imagery (Neldner *et al.* 1995, 2012). Figure 1 shows the geographic distribution and density of QHRESM program BRI collections. It can be seen that the collections have been made across the whole of Queensland, including a large number of the offshore islands. This is supported by Figure 4 which demonstrates a consistent contribution of at least 15% (up to 52%) of the specimens for a Pastoral District coming from the QHRESM program. The focus areas of the QHRESM program at various time periods described earlier can be clearly seen in Figure 1.

High quality fertile specimens of many (conservation) Least Concern species collected in surveys are discarded after name verification, as there are already adequate specimens for that area in the herbarium. However for Threatened taxa, 2090 specimens (2.3% of all QHRESM collections) of species listed under the *Nature Conservation Act 1992* (http://www.legislation.qld.gov.au/LEGISLTN/CURRENT/N/NatureConA92.pdf) were lodged in the Herbarium to improve knowledge of the distribution of these threatened plants. 52% of the plant taxa listed as threatened have been collected by the QHRESM program with 95 species of Endangered, 224 species of Vulnerable and 244 species of Near Threatened plants collected. In Queensland, herbarium collections of listed species under the *Nature Conservation Act 1992* are buffered with the remnant vegetation coverage to provide the essential habitat coverage that is used in regulating clearing under the *Vegetation Management Act 1999* (http://www.legislation.qld.gov.au/LEGISLTN/CURRENT/V/VegetManA99.pdf).

Herbarium specimen and ecological site data are used to define the area of occurrence and extent of occupancy of species assessed under the IUCN criteria (IUCN 2001) to determine conservation status. The increased knowledge of the distribution of Queensland plants has been the primary factor that has allowed for the downgraded listing of 116 formerly *Nature Conservation Act 1992* listed species over the last 5 years. Neldner (1993b) documented how the additional specimen data collected through the Cape York Peninsula survey and vegetation mapping project led to the delisting of *Neofabricia mjoebergii, Neofabricia sericisepala* and *Decaschistia peninsularis*. Of the 18 Queensland plants de-listed from the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999* on 23 May 2013 and 14 December 2013 http://www.environment.gov.au/cgi-tmp/publiclistchanges.5b2453194e7b93cb2e3f.html, all apart from *Commersonia argentea*, had at least one BRI specimen collected through the QHRESM program. Species with five or more QHRESM BRI specimens (Number of CORVEG site records in brackets) were *Acacia ramiflora* (16), *Bothriochloa biloba* (3), *Brachychiton vitifolius* (14), *Croton magneticus* (1), *Digitaria porrecta* (1) and *Jedda multicaulis* (1).

Herbarium specimen records are used extensively for modelling species distributions and scenarios such as the potential impacts of climate change. Rivers *et al.* (2011) have found that at least 15 specimen locations are required to build accurate range estimates of plant distributions, while Feeley and Silman (2011) found that extra specimens and more systematic collecting is required to accurately model and map species ranges. As can be seen in Figures 1 and 4, the QHRESM program has contributed a large amount of systematic data across Queensland, which is made available to governments, researchers and the general public world-wide through Australia's Virtual Herbarium, the Atlas of Living Australia and the Australian Ecological Knowledge and Observation System (AEKOS) (TERN 2013).

Species distribution and population models are useful for assessing the conservation status, population health and threats to species. Reliable locational data and specimen identification are core to achieving successful models. At each CORVEG site, measures of abundance are recorded for different plant lifeforms: basal area, stem density and cover for trees; stem density and cover for shrubs; and cover for herbaceous plants. These abundance data, together with comprehensive locational and landscape data, represent presence and absence data for suitable taxa. These presence-absence data provide opportunities for more robust species distribution and population modelling (Barry & Elith 2006). Guerin and Lowe (2013) used Generalized Additive Modelling (GAM) of ecological site data to produce robust models of species distribution. Presence-absence data is useful to evaluate the predictions of models derived from presence only data (Elith *et al.* 2006).

The survey and mapping program has been focused on the native vegetation, and particularly sites in the best-on-offer condition. However, the survey method requires all plant species to be recorded at a sample site. Hence the program has also greatly increased our knowledge of the distribution of the non-native flora. Table 1 shows that 10.4% (9205) of BRI specimens collected by the QHRESM program are non-native species. Table 2 documents that over 30% of the non-native specimens came through the QHRESM program. Families where the non-native species make a significant proportion of the collections include Solanaceae (33% of QHRESM collections), Asteraceae (28%), Caesalpiniaceae (21%), Amaranthaceae (20%), Malvaceae (20%) and Apocynaceae (17%). Two species of naturalised *Pinus* species and five species of non-native ferns have been collected. The most frequently collected non-native species were *Passiflora suberosa* L. (73 specimens), *Passiflora foetida* L. (72) and *Cynodon dactylon* (L.) Pers. var. *dactylon* (71).

Additionally the CORVEG database contains thousands of records of non-native species that can be used for modelling distribution and populations. As the CORVEG sites are located in the minimally disturbed sites and record quantitative abundance data, they can provide an assessment of impact of non-native species on native vegetation, e.g. percentage of non-native cover which is indicator in the BioCondition assessment method (Eyre *et al*. 2011). CORVEG data can complement specimen data in documenting the spread over time and space of environmental weeds.

Conclusions

Over the past 43 years, the QHRESM program has contributed almost 90000 (89389) specimens to BRI Herbarium accounting for 28% of all specimens added to BRI during this period. These specimens have been collected across all bioregions, pastoral districts and vegetation communities across the state using a systematic sampling approach driven by the requirement to comprehensively sample all vegetation communities. The QHRESM BRI specimens represent more than 79% of the total native and 73% of the naturalised vascular flora of Queensland, and make a valuable contribution to the collections of bryophytes, lichens and liverworts. The data and specimens collected enhance the ability to assess local, state and continental scale plant diversity through improved distribution information and ecological knowledge, and provide material for more comprehensive plant taxonomy at both the morphological and genetic level.

The contribution of the QHRESM program is going to be greater than stated in this paper because the survey and mapping program is not yet completed. Furthermore there is a backlog in getting specimens into BRI for completed projects, and a significant lag in describing new species. In summary the data collected as part of the QHRESM program provides a long term legacy that undoubtedly will be used by botanists, ecologists, governments and the public for long into the future.

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Lysimachia mauritiana (Primulaceae) on seacliffs in the eastern suburbs of Sydney: a new naturalised record for Australia

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Abstract: *Lysimachia mauritiana* Lam. (family Primulaceae), a small short-lived herb native to India, Indian and Pacific Ocean islands, and coastal east Asia, is described as a new naturalised record from the eastern suburbs of Sydney, New South Wales, Australia. It was first recorded in 1981 near Coogee, and grows in exposed rock crevices and seepages on the seacoast, very similar to its natural habitat overseas. *Lysimachia mauritiana* is known to have been cultivated in the area in 1961 in a home garden, which is the likely source of this introduction; it appears to be spreading locally as a weed.

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Introduction

Based on phylogenetic analyses of the *Lysimachia* complex (Manns & Anderberg 2005, 2009, and references therein) the boundaries of the genus *Lysimachia* (family Primulaceae; sometimes placed in Myrsinaceae) have recently been enlarged to include species previously regarded as members of other genera, including *Anagallis*, *Pelletiera* and *Trientalis*, along with previous combinations made for *Asterolinon* and *Glaux*. These changes affect several *Anagallis* species occurring in Australia (one native, several naturalised) and have been accepted in the *Australian Plant Census* (CHAH 2014) but not currently adopted in the *New South Wales Flora Online* (The Royal Botanic Gardens and Domain Trust 2014).

Within the original concept of *Lysimachia*, three taxa have been regarded as native or introduced in New South Wales: *Lysimachia fortunei* Maxim., *Lysimachia japonica* Thunb. and *Lysimachia vulgaris* var. *davurica* (Ledeb.) R.Knuth; the latter two also occurring in Victoria (see Kodela 2006). Three other taxa (which are usually considered naturalised) occur or have been recorded in southern Australia: *Lysimachia linum-stellatum* L. (Western Australia, South Australia, Victoria), *Lysimachia nummularia* L. (Victoria, Tasmania) and *Lysimachia vulgaris* L. var. *vulgaris* (Victoria) (CHAH 2014; see also state and territory floras and plant censuses). We report here the occurrence of an additional species in Australia, *Lysimachia mauritiana* Lam., as naturalised in New South Wales.

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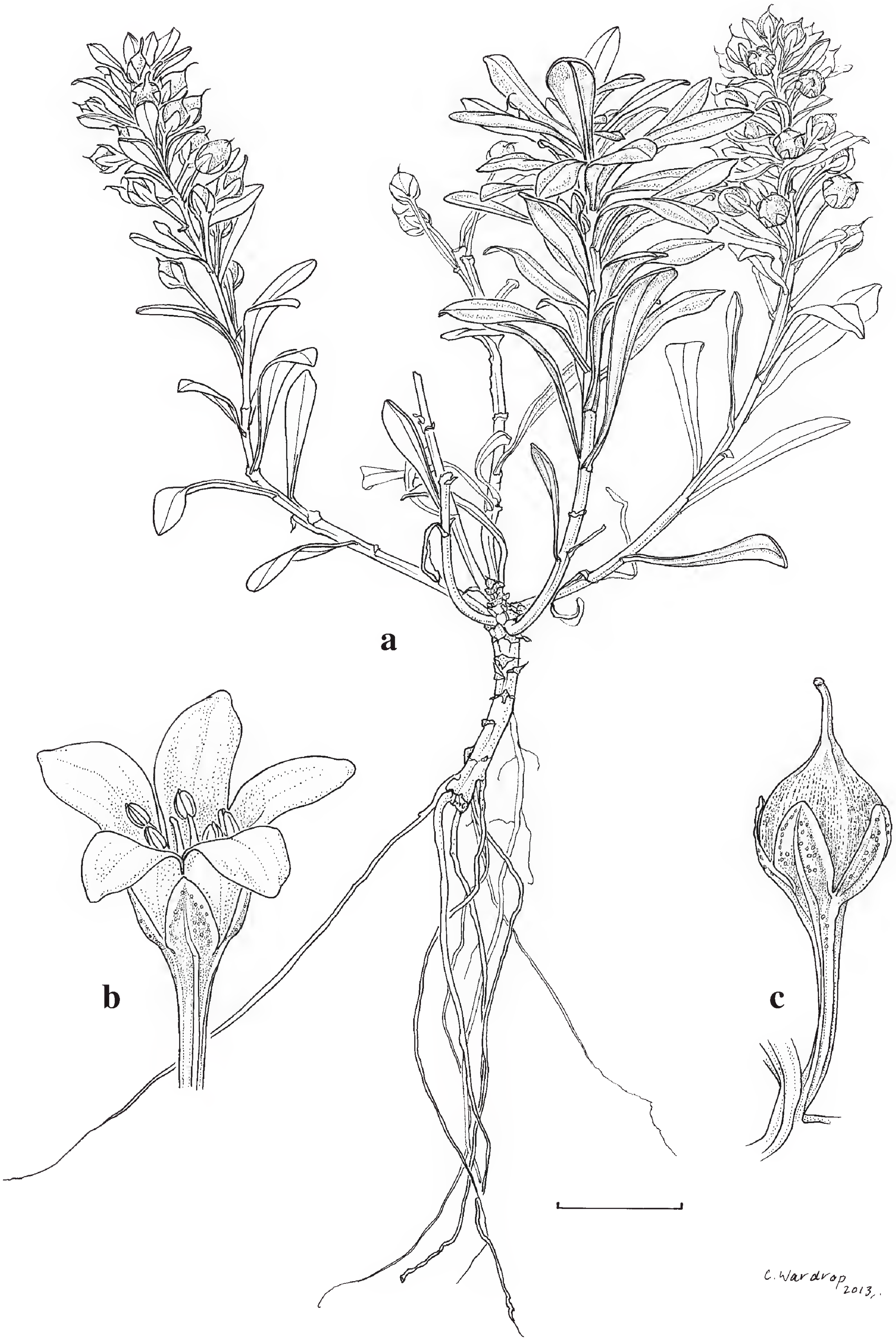

Fig. 1. *Lysimachia mauritiana*: **a,** habit; **b,** flower; **c,** fruit. Vouchers: a, c, *Leary NSW976851*; b, *Leary NSW975610*. Scale bar: a = 2.5 cm; b, c = 0.5 cm.

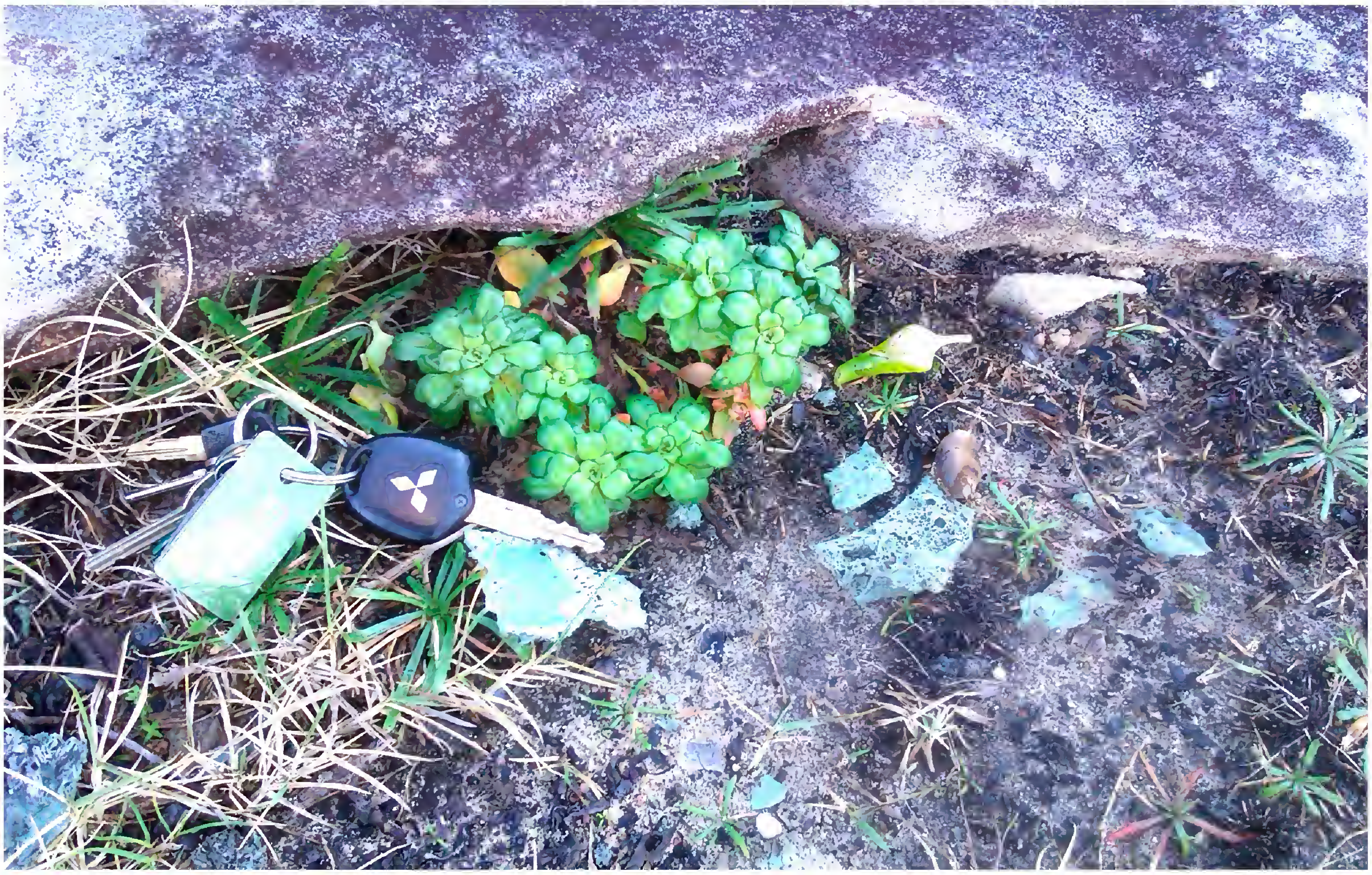

Fig. 2. Young plants growing on Clovelly headland, Burrows Park. Photo: M. Leary, July 2013.

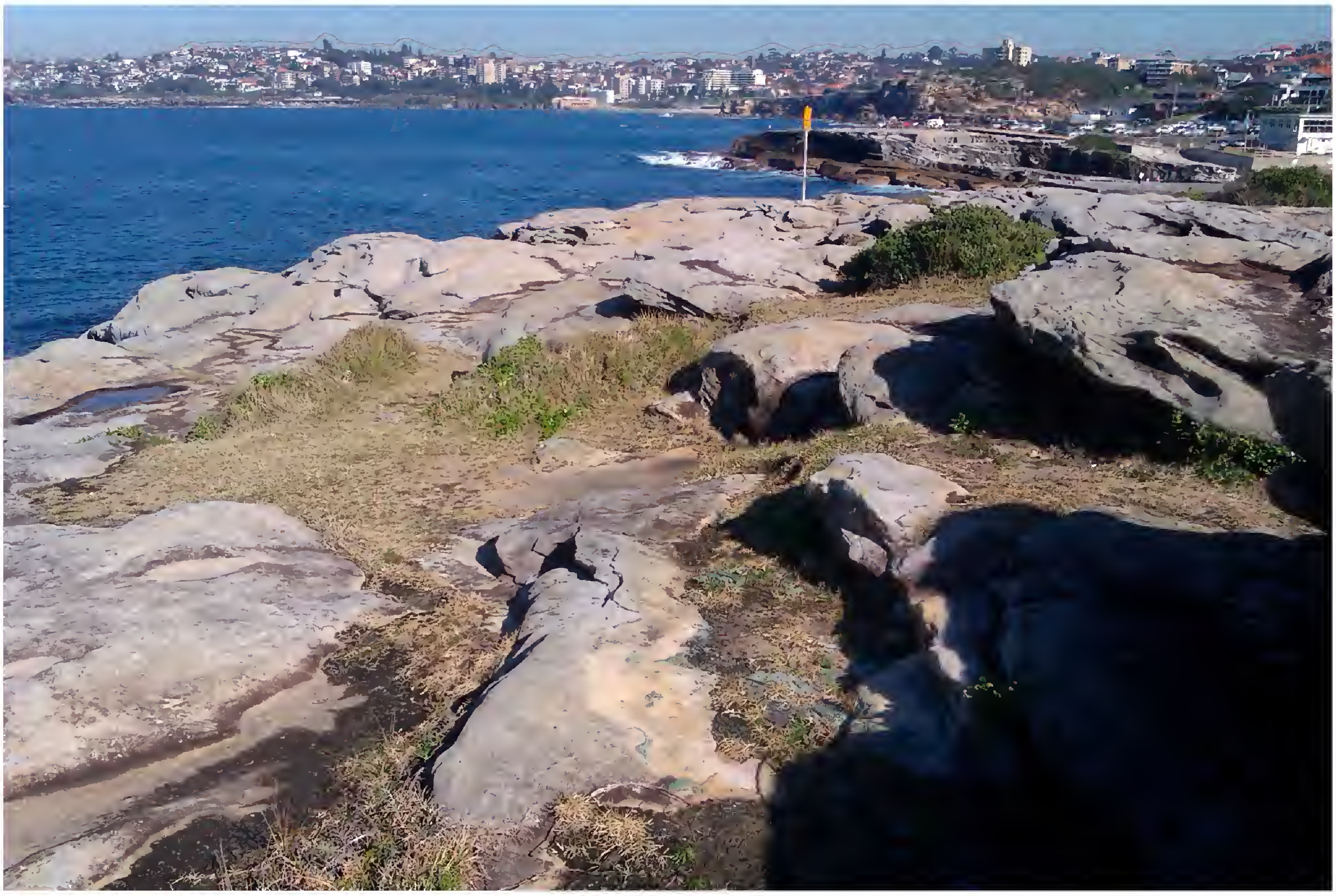

Fig. 3. Sandstone headland habitat at Burrows Park, Clovelly. Photo: M. Leary, July 2013.

Although more common and widespread in the Northern Hemisphere, the occasional and often ‘spotted’ distribution of new *Lysimachia* records in Australia cannot be assumed to be naturalised records resulting from human introductions and activities. For example, the presence of *Lysimachia fortunei* in Werrikimbe National Park, first recorded in 2003, is possibly a ‘natural adventive’ distribution associated with long distance-dispersal, based on similar distribution patterns in *Lysimachia vulgaris* var. *davurica* (Kodela 2006). In the case of *Lysimachia mauritiana* recently recorded in eastern Sydney there is, however, clear evidence of human activity being the source of its introduction which has led to it spreading as a garden escape.

Methods

The investigation employed the use of specimen collections, field studies and plant record searches. The description is based on morphological observations of herbarium specimens held at NSW in conjunction with literature research (Bentvelzen 1962, Kao & DeVol 1978, Yamazaki 1993, Hu & Kelso 1996). Garden “living” collection records, including seed accessions, at the Royal Botanic Gardens, Sydney, were searched and assessed. A search (including the internet) of commercial nursery guides and catalogues in Australia was conducted, but further investigation of more historical records and archives might reveal additional information.

Taxonomic description

Lysimachia mauritiana Lam., *Encycl. [J. Lamarck & al.]* 3(2): 592 (1792)

Lubinia mauritiana (Lam.) Spreng., *Syst. Veg. (ed. 16) [Sprengel]* 1: 572 (1825)

Lubinia spathulata Vent., *Descr. Pl. Nouv*. t. 96 (1800); *Lysimachia spathulata* (Vent.) Schouw., *Linnaea* 24: 160 (1851), *fide* Bentvelzen (1962)

?*Lysimachia glaucophylla* Hook. & Arn., *Bot. Beechey Voy*. 306, t. 68 (1838), *fide* Bentvelzen (1962)

Lysimachia lineariloba Hook. & Arn., *Bot. Beechey Voy*. 268 (1838); *Lubinia lineariloba* (Hook. & Arn.) Pax in *Nat. Pflanzenfam. [Engler & Prantl]* 4, 1: 112 (1897), *fide* Bentvelzen (1962), Hu & Kelso (1996)

Lysimachia lubinioides Siebold & Zucc., *Abh. Math. – Phys. Cl. Königl. Bayer. Akad. Wiss*. 4(3): 140 (1846); *Lubinia lubinioides* (Siebold & Zucc.) Pax in *Nat. Pflanzenfam. [Engler & Prantl]* 4, 1: 112 (1897), *fide* Bentvelzen (1962)

Lysimachia nebeliana Gilg ex Gilg & Loes., *Bot. Jahrb. Syst*. 34 (1, Beibl. 75): 57 (1904), *fide* Bentvelzen (1962), Hu & Kelso (1996)

Herb, biennial or short-lived perennial; stolons stout, short; *stems* solitary or tufted/many, ascending to erect, 10–40 (–50) cm high, stout, terete, slightly fleshy, simple or shortly branched above, glabrous, minutely black-dotted (i.e. with

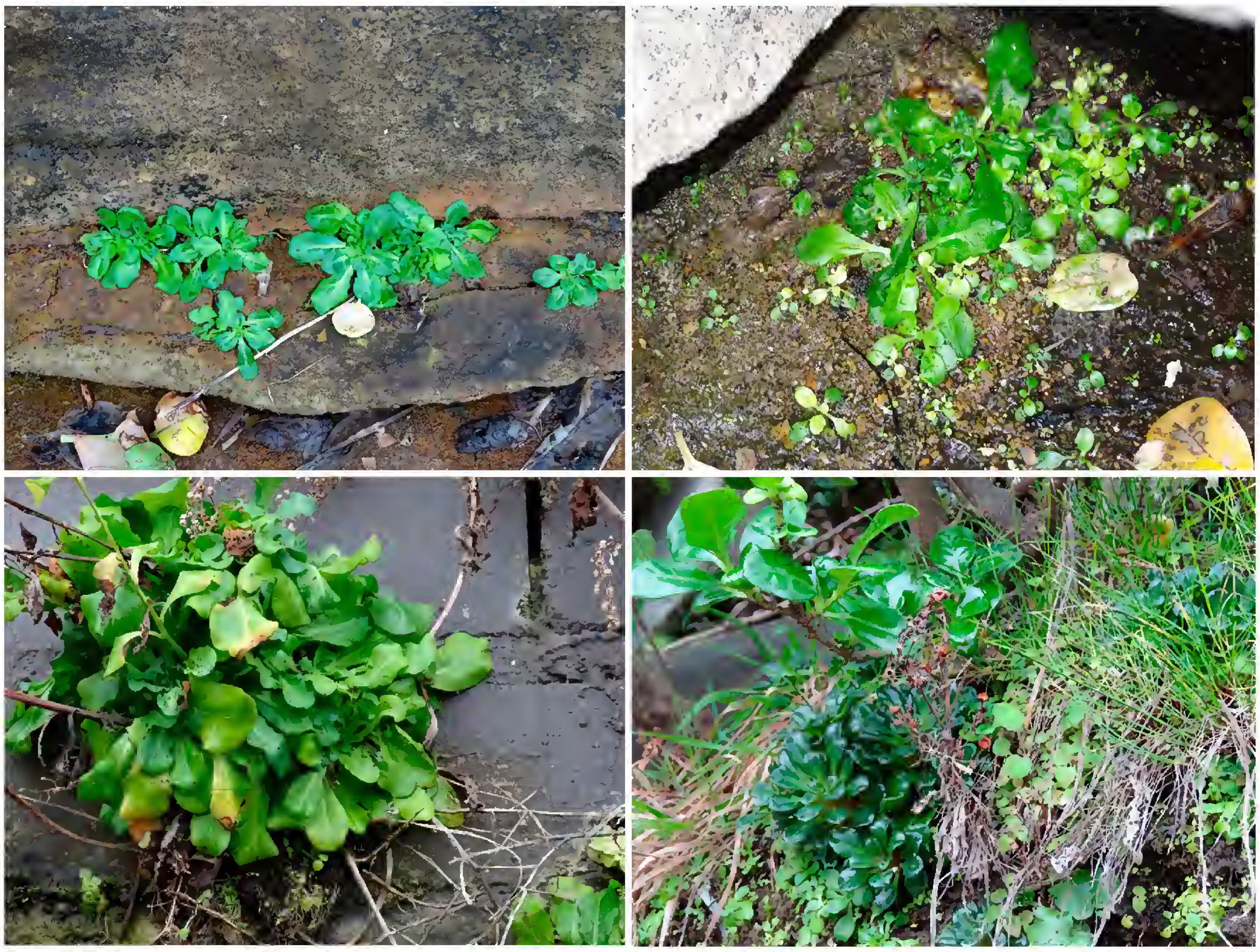

Fig 4. Plants at Lurline Bay, Coogee. Photos: P. Adam, August 2013.

black glands or glandular dots). *Leaves* alternate, lower leaves shortly petiolate, long-attenuate at base, mostly 2–5 cm long and 5–12 mm wide, upper leaves sessile or nearly so, shortly attenuate at base, mostly 1.5–2 cm long and 9–14 m wide; lamina slightly fleshy, glabrous, black glandular punctate, oblong-obovate, obovate or spathulate, apex subrounded or obtuse to subacute, midrib prominent, lateral veins obscure, margin entire, narrowly revolute; leaf bases persistent on stems after shedding of leaves, outer rims of petioles carried on as decurrent narrow ridges down stems (at least in dried material). *Racemes* leafy, erect, terminal, often compound-paniculate, initially coniform, gradually elongating, many-flowered, 3–15 cm long, lower bracts spathulate, identical to leaves except for shorter petiole, gradually reduced upward (corymbose at flowering/raceme-like in fruit); *pedicels* 5–15 (–25) mm long, about as long as or slightly shorter than the leaf-like bracts, glabrous. *Flowers* 5-merous; *calyx* 3.5–5 mm long, deeply divided, lobes broadly lanceolate to elliptic (or ±oblong), with midrib, black glandular-punctate, margin membranous whitish-hyaline, apex subacute to obtuse; *corolla* white to pinkish, tube 2–3.5 mm long, petals 5–6 mm long, the lobes narrowly obovate or ligulate-oblong, (with a few glandular dots at obtuse apex). *Capsules* globose-ovoid, yellow to reddish brown, 4–6 mm diam., lightly pitted, glabrous, stigma/style persistent, longitudinally dehiscing by valves, many-seeded. Figs 1, 2 & 4.

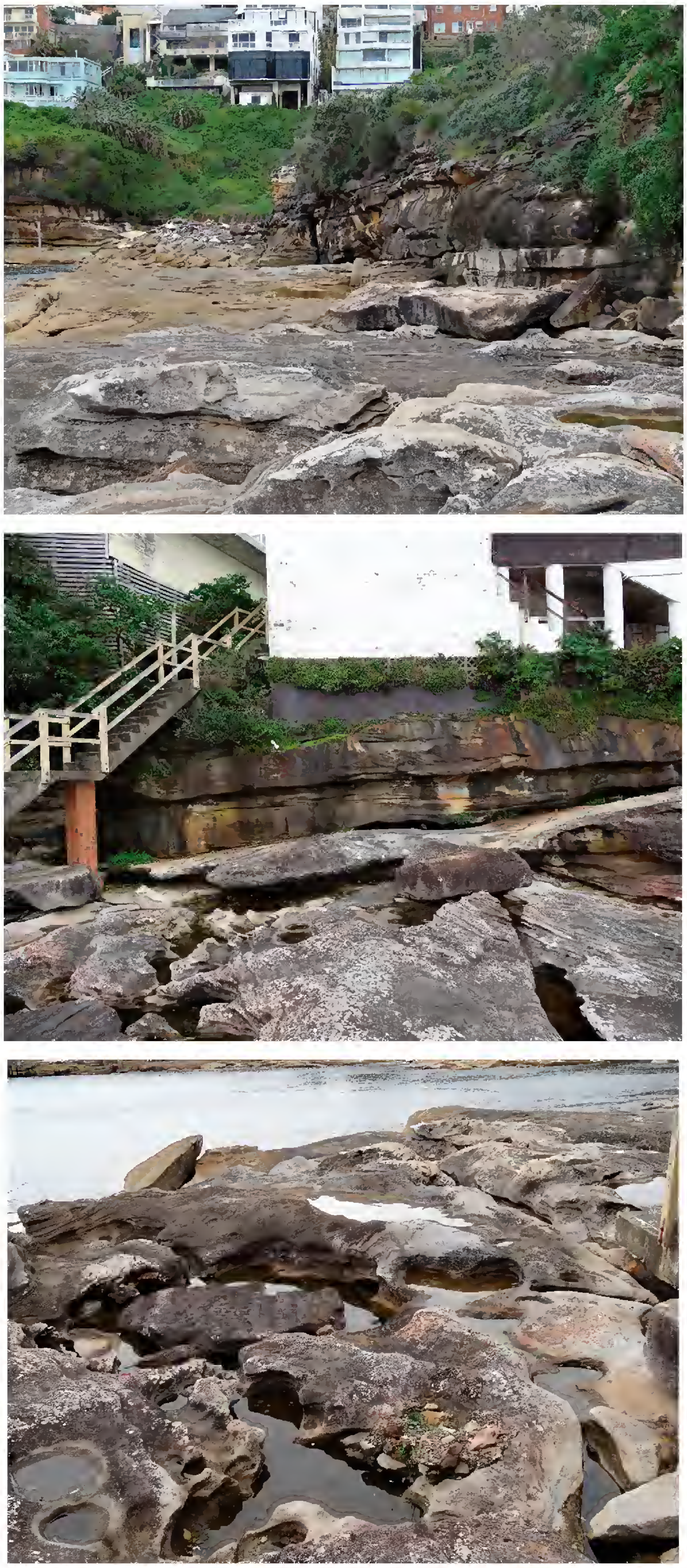

Fig. 5. Cliff seepage and rock platform habitats at Lurline Bay, Coogee. Photos: P. Adam, August 2013.

***Flowers*:** much of summer and autumn.

***Habitat*:** in overseas floras the habitat is reported as seashore, near beaches, headlands, in coastal regions; often growing in rock crevices and seepages; recorded in New South Wales on an exposed coastal headland, near cliff edge in cracks and pockets of skeletal soil on sandstone (Fig. 3) and in wet seeps in sandstone on a rock platform and adjacent cliff face (Fig. 5).

***Distribution*:** in Australia recorded from near the coast in the Coogee – Clovelly area of eastern Sydney, Central Coast, New South Wales; native to India, Indian Ocean Islands (including Mauritius, Reunion), Korea, China, Taiwan, Japan, the Ryukyus, Pacific Ocean Islands (including Hawaii, Philippines, New Caledonia).

***Specimens examined*:** **Australia:** New South Wales: Central Coast: Lurline Bay, South Coogee, 8 Feb 1961, *K. Mair s.n.*, [cultivated] seed ex Ichijoji, Kyoto (intro.786) (NSW826818); Lurline Bay, 14 Dec 1982, *P. Adam* (NSW826820, UNSW14706); Burrows Park, Clovelly headland, Apr 2011, *M. Leary* (flowering branchlet) (NSW975610); Burrows Park, Clovelly headland, Apr 2012, *M. Leary* (fruiting plant) (NSW976851). **Japan:** Hondo: Shirahama in Kii, May 1953, *T. Koyama s.n.* (NSW826821 ex TSM); Shizuoka Pref., Shimoda-shi, Susaki, 22 Jun 1974, *J. Murata 27* (NSW826822 ex TI).

***Common names*:** the English common name often used overseas is Spoonleaf Yellow Loosestrife, which is misleading (and not recommended) since *Lysimachia mauritiana* has white flowers; also known as Ocean Primrose.

***Notes*:** Distinguished from other species of *Lysimachia* in New South Wales by the slightly fleshy, often narrowly spathulate leaves, and flowers with white petals with apex acute to obtuse (petals more broadly rounded in *Lysimachia fortunei*; petals yellow in *Lysimachia japonica* and *Lysimachia vulgaris* var. *davurica*). Overseas floras indicate that the leaves in *Lysimachia mauritiana* may be larger than that described above. As seen in Figures 2 and 4, young plants often have a rosette form (rosette-like arrangement of leaves), and the basal leaves in plants are often broader than those on the stems of more mature, taller plants like the one illustrated in Figure 1. Plants at a quasi-rosette stage of growth might occasionally flower.

Several varieties are sometimes recognised, including *Lysimachia mauritiana* var. *rubida* (Koidz.) T.Yamaz., *Fl. Jap.* (Iwatsuki *et al*., eds.) 3a: 83 (1993) (based on *Lysimachia rubida* Koidz., *Bot. Mag. (Tokyo)* 33: 110 (1918)) and *Lysimachia mauritiana* var. *taiwaniana* S.S.Ying, *Colour. Illustr. Pl. Taiwan*, Pt 4; *Colour. Illustr. Herbac. Pl. Taiwan* 1: 155 (1980).

Discussion and Conclusion

Introduction and spread of Lysimachia mauritiana in eastern Sydney

Lysimachia mauritiana has a widespread distribution in coastal habitats in the Indian and Pacific Oceans and Asia, and the coastal habitat makes the species a likely candidate for dispersal in ocean currents (Kono *et al.* 2012) or by the agency of shore birds.

The habitats of the collections from Lurline Bay, South Coogee, and Burrows Park, Clovelly, in eastern Sydney, are similar to those in which the species occurs overseas. But while natural dispersal to Australia cannot be ruled out, there is evidence for a more parsimonious explanation – that it is a human introduction. Through international seed exchange a sample of *Lysimachia mauritiana* was provided to the Royal Botanic Gardens, Sydney, from Kyoto, Japan (RBGS Nursery index card record: 16 September 1958 [accession] from Kyoto Takeda Herbal Garden, Ichijoji), for cultivation as part of the Garden's living collection. Some of this seed was sown by former Director Mr Knowles Mair in his home garden in South Coogee. This is indicated by a cultivated specimen (*NSW826818* in the National Herbarium of New South Wales) collected in 1961 from his garden. The location of the garden is a few hundred metres north of the Lurline Bay site though this history was not known to us when the Lurline Bay population was first observed in winter 1981 (P. Adam, *pers. obs*.) and collected in flower the following year; given the proximity it seems probable that the population represents a naturalised 'escape' from the earlier garden planting.We are not aware that *Lysimachia mauritiana* has ever been commercially available in Australia through the nursery trade.

It is likely that the Clovelly population has arisen from seed transported from Lurline Bay, which is c. 2.5 km directly south. The seeds are small, buoyant and could be thrown by breaking waves onto the headland. While the possibility of dispersal and subsequent successful establishment will have been low, this is a credible explanation for its occurrence. We are not aware of its occurrence in any nearby garden in Clovelly.

The range extension suggests that as further expansion in distribution may occur in the future, botanical collectors visiting supratidal rock platforms and seacliffs should be aware of the possibility of the occurrence of *Lysimachia mauritiana* and report new localities. Despite the widespread occurrence of introduced species on seacliffs, strandlines and beaches, the impact of introductions on the native flora of these habitats has been little studied. There is no clear evidence as to whether introductions have caused declines in native species, but at the microsite level pre-emption of space by an introduced species may reduce the availability of locations which might otherwise be available for establishment of native species.

The possible spread of plants from Knowles Mair's South Coogee garden source is further supported by the following extract from his obituary (Chippendale 1999):

"His own gardens reflected some of his thoughts. They were never neat, landscaped affairs; rather, they were crammed with a wide variety of plants, exotic and native, and incorporated individual pools carved in sandstone especially for his granddaughters. When he was living at South Coogee, he referred to his seaside garden as the South Coogee Research Station, where he had great interest in seeing which species could withstand the sea spray."

Another naturalised weed, *Crithmum maritimum* L. (Apiaceae), with scattered small populations in the same area (and in the Illawarra), and appears to be spreading, may have been introduced in a similar way as *Lysimachia mauritiana*. There is a cultivated specimen in the National Herbarium of New South Wales collected from South Coogee by K. Mair, 8 March 1962, which had been grown from seed ex Genoa ([Royal Botanic Gardens accession] introduction 746, July 1958). It is likely that both taxa were part of Mair's "experiments" of species' tolerance to sea spray and were grown in his garden from seed sourced from overseas that correspond to past accessions for Living Collections at the Royal Botanic Gardens, Sydney (evidence from old Nursery record cards).

Mair's garden introductions may well be the source of other naturalised species' populations in the Coogee – Clovelly area. In the last few decades there has been an increased awareness of weeds and garden plantings. To help avoid potential problems with adventive or hazardous plants the Royal Botanic Gardens & Domain Trust, Sydney, currently has in place a policy and procedures to undertake weed risk assessments for new living accessions and taxa proposed for repropagation. Local councils and community bush regeneration groups require continued support for their programs discouraging the growing of potentially invasive plants, and removal where they occur.

Kono *et al*. (2012) discuss considerable karyotypic variation in *Lysimachia mauritiana*. If this species was found to occur elsewhere in Australia, for example in the far north where there is perhaps a slightly greater possibility of 'natural' arrival, then karyotype and molecular evidence might be a way of determining whether there are multiple introductions from different sources.

Seacliff introductions

The seacliff environment would generally be regarded as harsh. Nevertheless, in, or close to, human settlement seacliffs provide habitat for many introduced species, often of horticultural origin. For example, describing cliff vegetation near Christchurch, New Zealand, Healy (1959) concluded “The communities are now, in effect, living relics of horticultural subjects fashionable with earlier generations of gardeners”. A similar conclusion could be reached concerning cliffs in New South Wales (Adam *et al.*1989), Victoria (Kirkpatrick 1974) and Northern Europe (P. Adam, *pers. obs.*).

The success of introduced species on cliffs may appear surprising given the apparently harsh environmental conditions. However, many of the species concerned are, like *Lysimachia maritianum*, coastal species in their native habitats. A surprisingly large number of widespread garden plants (both vegetables and ornamental plants grown for their flowers) are of coastal origin – their hardiness being one of their virtues as garden plants. Other coastal species have been transported in ships’ ballast – stones collected from near ports to stabilise vessels sailing without cargo, and discharged at other ports where cargo was loaded. With the stones, seeds and other propagules could be transported between countries. Today the most widely used form of ballast is seawater; this is unlikely to contain viable seeds, although it is a major means for the transport of marine organisms.

Cliffs often do not have continuous vegetation cover, and available niches for plants may be small and spatially disjunct, but frequently include perennial seepage zones. A propagule reaching such a niche may be able to develop free from competition from established plants; this may be an additional factor permitting the establishment of introduced species.

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We thank Matt Leary, Randwick City Council, for bringing recent attention to this species, and providing specimens and information on the Clovelly population. Fig. 1 was kindly drawn by Catherine Wardrop. Details on Knowles Mair’s former garden was kindly provided by Ian MacDonald with the assistance of Merle Johnson and Barbara Briggs. Peter Hind assisted with an explanation of details provided on cards in the early plant accession card system at the Royal Botanic Gardens, Sydney.

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Floodplain vegetation of the River Murray in 1987–1988: an important pre-drought benchmark for subsequent studies

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Abstract: As part of a wider study of floodplain vegetation along the River Murray, we carried out a field survey in 1987–1988 involving collection of floristic and vegetation condition data from 335 sample plots (each 400 m^2 in area), between Hume Dam and Lake Alexandrina (including the Edward-Wakool anabranch system). The floodplain vegetation is dominated by just two tree species, River Red Gum (*Eucalyptus camaldulensis*) and Black Box (*Eucalyptus largiflorens*), but the composition of the understorey shows much greater variation, both along the river and across the floodplain. A total of 499 plant species, subspecies and varieties were recorded from the survey plots, of which 316 (63%) were native and 183 (37%) were exotic. From analysis of the floristic data we identified 37 vegetation communities, not including the vegetation of permanent wetlands and cleared areas; 21 communities were distinguished in the River Red Gum zone, 12 communities in the Black Box zone, and 4 communities on rises within the floodplain. The main floristic division among the River Red Gum communities was between Riverine Plain/ Headwaters Zone communities of the upper Murray, and Mallee Zone communities of the lower Murray. Among the Black Box communities, the main floristic division was between inner floodplain communities and outer floodplain communities, with a further division between South Australian communities and New South Wales/Victorian communities. Major factors influencing the floristic patterns included flooding frequency/duration and soil salinity.

Eucalypt health declined steadily downstream and was poorest in the lower reaches of the river below the Darling Junction, where 60% of the trees were healthy, 18% unhealthy (at least 40% of the canopy dead) and 22% dead. By comparison, at the upper end of the river, above Tocumwal, 84% of the trees were healthy, 14% unhealthy and only 2% dead. Overall, the condition of Black Box trees (44% unhealthy or dead) was worse than the condition of River Red Gum trees (29% unhealthy or dead). Eucaypt regeneration was also poorest below the Darling Junction, with regenerants present in 77% of plots upstream of the Darling but only 35% of plots downstream. The findings of poor tree health and sparse regeneration below the Darling coincide with the most heavily regulated part of the Murray, where the reduction in flooding due to upstream storages and water extraction, mainly for irrigation, has been greatest. Black Box regeneration was much sparser overall than River Red Gum regeneration (regenerants present in 69% of River Red Gum plots but only 29% of Black Box plots). The poor condition of the Black Box trees, coupled with their poor regeneration, suggests that the long-term future of this species along the Murray, particularly below the Darling Junction, is tenuous, even though it is a dominant component of the vegetation.

The integrity of floodplain vegetation along the Murray has been severely compromised by weed invasion. Weeds were common throughout the survey area, but were most prevalent in the climatically wetter sections of the river, at both the downstream and upstream ends (below Mannum and above Tocumwal). The median number of exotic species per plot equalled or exceeded the number of native species in these sections of the river, whereas native species outnumbered exotic species in the other river sections. Communities of the River Red Gum zone and the rises were generally weedier than those of the Black Box zone. Exotic species strongly influenced the community classification. They were the dominant overstorey species in two communities (*Salix* species – willows) and outnumbered native

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species in the understorey of another eight communities. At the lower end of the river, below Mannum, the River Red Gums that originally fringed the river had been mostly replaced by dense thickets of the exotic Weeping Willow, *Salix babylonica*.

Other factors that have impacted on the floodplain vegetation at the plant community level have been river regulation and soil salinisation. Stabilization of water levels in the lower Murray by construction of a series of weirs and barrages has favoured the spread of some communities at the expense of others. The favoured communities, which are characterised by stands of Common Reed, *Phragmites australis*, along the water's edge, appear to be artefacts of river regulation. Salinisation has resulted in death of eucalypts and replacement of eucalypt communities by shrub communities dominated by samphires, *Tecticornia* species. The samphire community characteristic of the most saline sites is one of the most species-poor communities on the Murray floodplain.

Logging along the Murray in New South Wales and Victoria has resulted in extensive replacement of old growth River Red Gum forests and woodlands by more even-aged stands of straight young trees. Following the recent conversion of many areas of State Forest along the Murray in both New South Wales and Victoria to National Park or Regional Park, and thus the cessation of logging in these areas, they should now revert gradually to mature forest and woodland.

This study is the first to describe broad scale floristic patterns in the floodplain vegetation of the Murray covering most of the length of the river. It also provides data on the vegetation condition in the 1980s, and provides a benchmark of conditions before the prolonged Millenium Drought in south-eastern Australia from 1997 to 2010. More recent surveys of vegetation condition have reported a severe decline in tree health during the drought. The results from our 1987–88 survey are important because they show that the deteriorating condition of the vegetation was already evident in the 1980s and although exacerbated by the subsequent drought, it is not just a consequence of that drought. The results are consistent with the conclusion that the primary cause of the decline has been river regulation and water extraction for irrigation. The rate of deterioration has increased rapidly since the 1980s because of the drought. There has been some improvement since the breaking of the drought, but the poor condition of the River Murray floodplain vegetation, an Australian icon, remains a major conservation and management issue. The impacts of climate change – higher temperatures and reduced rainfall – have compounded the problem and will continue to do so at an increasing rate. The results of the study support listing of the floodplain vegetation of the lower reaches of the river as a critically endangered ecological community.

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Introduction

The River Murray and its tributaries form the largest river system in Australia, with a catchment, the Murray-Darling Basin, covering nearly one seventh of the continent. The Murray flows some 2530 km through New South Wales, Victoria and South Australia, from its source in the Great Dividing Range to its mouth on the Southern Ocean (Mackay and Eastburn 1990). Water flow in the Murray is low compared with rivers of similar catchment size on other continents, and it is highly variable (Young 2001). Over the last two centuries, its waters have become increasingly regulated, especially since the 1920s, largely to support irrigated agriculture (Close 1990, Maheshwari *et al.* 1995). The Murray system is now controlled by many dams and weirs, and water from the Snowy River has been diverted westward across the Great Dividing Range to augment the Murray flow. However, the economic and social benefits of this control and use of the Murray's waters have had major environmental costs through declining river health, including hydrological, geomorphological, salinity and water quality impacts, as well as impacts on fish, aquatic invertebrates, floodplain vegetation and wetland biota (Walker and Thoms 1993, Thoms *et al.* 2000, Kingsford 2000, Gippel and Blackham 2002, Gehrke *et al.* 2003, Davies *et al.* 2008, Jensen and Walker 2012).

Existing levels of water use are clearly unsustainable. In 2002 the Living Murray restoration program was established to facilitate recovery of water to improve environmental conditions at a series of icon sites along the river (Murray-Darling Basin Authority 2011). More recently, a Basin Plan has been adopted for integrated management of the waters of the Murray-Darling Basin (Commonwealth of Australia 2012). The intention of the Basin Plan is to optimise social, economic and environmental outcomes from use of the Basin water resources. The environmental objective is healthy and resilient ecosystems with rivers and creeks regularly connected to their floodplains and, ultimately, the ocean. However, the capacity of the Basin Plan to deliver a healthy working river system has been questioned (e.g. Cosier *et al.* 2012).

The River Murray Riparian Vegetation Study, undertaken between 1987 and 1989, was commissioned by the then Murray-Darling Basin Commission to provide baseline information on floodplain vegetation patterns and vegetation condition along the Murray (Margules and Partners *et al.* 1990, Smith and Smith 1990). The study results were provided as a report and as geographic information system mapping. While this information has been used, for example, by Benson *et al.* (2006) and Benson (2008) in their classification of New South Wales plant communities, it is not readily available. The present paper aims to disseminate the information more widely in the formal scientific record and describes the findings of the River Murray Riparian Vegetation Study in relation to floristic classification of the floodplain vegetation communities, which was the part of the study for which we were responsible.

Vegetation condition data were also collected during our field survey and are important because they document the condition of the floodplain vegetation in the 1980s, a period of relatively good rainfall before the 'Millennium Drought', a severe and prolonged drought in south-eastern Australia from 1997 to 2010 (Murphy and Timbal 2007, National Climate Centre 2010). A rapid decline in floodplain vegetation condition has been reported in more recent surveys carried out during the drought (Murray-Darlin Basin Commission 2003, Smith and Kenny 2005, Cunningham *et al.* 2009). The 1987–88 condition data that are analysed in this paper provide a benchmark to assess the subsequent impacts of the drought and to assess the impacts of river regulation and salinisation before the drought.

The floodplain vegetation of the Murray is an Australian icon, especially the characteristic tree, the River Red Gum, *Eucalyptus camaldulensis*. There have been many studies of ecological processes in this vegetation (e.g. Craig *et al.* 1991, Bren 1992, Thorburn and Walker 1994, Overton *et al.* 2006). However, descriptive studies of vegetation patterns on the floodplain have been fewer and have been limited in geographical extent (e.g. Chesterfield *et al.* 1984, Chesterfield 1986, Ashwell 1987, Roberts and Ludwig 1990) or have considered floodplain vegetation only as part of a broader vegetation survey (e.g. Frood 1983, Fox 1991, Scott 1992, Porteners 1993). The present study is still the only study that has described floristic patterns in the Murray floodplain vegetation over a wide geographical scale, covering most of the length of the Murray, including the Edward-Wakool anabranch system.

Survey Area

The survey area comprised the floodplains of the River Murray and its anabranches, including the Edward-Wakool river system, from below Hume Dam, downstream to the upper end of Lake Alexandrina (Fig. 1).

The Murray passes through three major geomorphic zones: the Headwaters Zone, Riverine Plain and Mallee Zone (Mackay and Eastburn 1990). The Headwaters Zone extends from the river's source near Mount Kosciuszko to about Corowa, corresponding to the tablelands and western slopes regions of the Great Dividing Range. The survey area included only the western end of the Headwaters Zone, from Hume Dam to Corowa. The Riverine Plain extends from Corowa to about Wakool Junction. This vast alluvial plain, formed under a different climate and hydrology from the present, has a characteristic anastomosing drainage and it is here that the Murray receives most of its major Victorian tributaries (Butler *et al.* 1973, Storrier and Kelly 1978). For the remainder of its course, the Murray flows through the Mallee Zone, which was formerly inundated by the sea and is characterised by sand dunes and highly saline groundwater (Bowler and Magee 1978, Storrier and Stannard 1980). Surface runoff after rain is insufficient to form a local stream system. The Murrumbidgee and Darling Rivers, the two major tributaries which join the Murray in the Mallee Zone, both come from better-watered regions.

These three broad zones can be further subdivided. In a survey of Murray wetlands, Pressey (1986) divided the floodplain between Hume Dam and Lake Alexandrina into eight sections based on differences in hydrology and geomorphology, but also corresponding to climatic differences (Fig. 1). Pressey's sections were used in the present study and are described below.

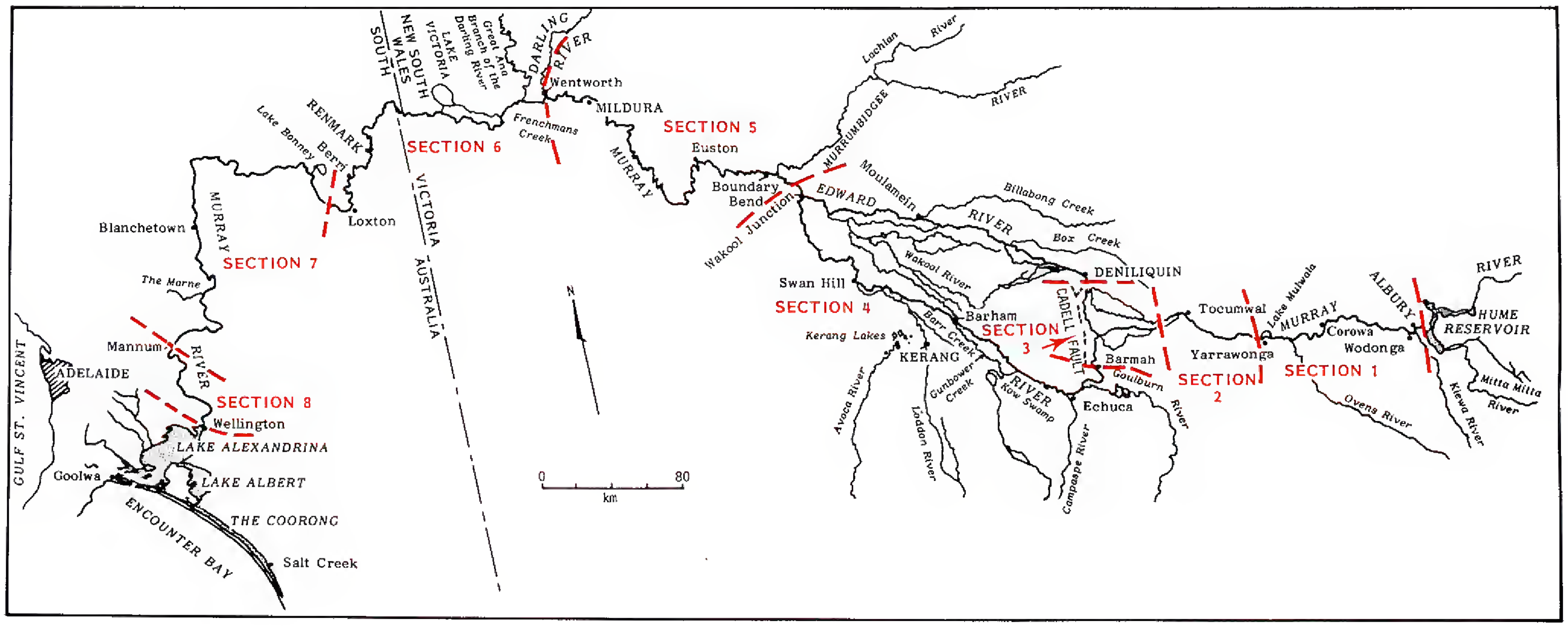


Fig. 1. Map of the River Murray showing the eight sections of the survey area.

Section 1

Floodplain of the Murray from Hume Dam to Yarrawonga Weir. A transition area between the Headwaters Zone and the Riverine Plain. River length is 233 km. The floodplain is relatively narrow, varying from 1.5 to 5 km wide, with a total floodplain area of 292 km^2 (statistics from Pressey 1986). The climate is cooler and wetter than in the other river sections, corresponding to Nix and Kalma's (1982) climatic subregion B12a. Mean annual rainfall is 500–650 mm, distributed fairly evenly through the year (data from Bureau of Meteorology).

Section 2

Floodplain of the Murray from Yarrawonga Weir to the downstream end of Ulupna Island, below Tocumwal. Forms part of the Riverine Plain. River length is 124 km, floodplain width is generally 2–3 km, and floodplain area is 164 km^2. Forms part of Nix and Kalma's (1982) climatic subregion B12b, with a generally warmer, drier climate than Section 1. Mean annual rainfall is 420–500 mm.

Section 3

Floodplain of the Murray from Ulupna Island to Barmah, and floodplain of the Edward River from the offtake to 3 km upstream of the Lawson Siphon, near Deniliquin. Also includes the Tuppal-Bullatale anabranch system. Forms part of the Riverine Plain. River lengths are Murray 108 km and Edward 51 km. Floodplain width varies from about 1 km at the upstream end to more than 25 km near the Edward offtake. Floodplain area is 1366 km^2. The climate is similar to Section 2, forming part of Nix and Kalma's (1982) climatic subregion B12b. Mean annual rainfall is 400–420 mm. The broad triangular floodplain and complex channel system are a consequence of the Cadell Fault, which runs roughly from Echuca to Deniliquin (Fig. 1). The uplifting of the Cadell Fault some 25 000 years ago blocked the westward passage of the Murray and brought about a division into the Edward flowing north of the fault and the present Murray flowing south (Bowler 1978).

Section 4

Floodplain of the Murray from Barmah to 11 km downstream of Wakool Junction, and floodplain of the Edward River below Deniliquin. Includes the extensive network of anabranches enclosed by the Murray and Edward Rivers, the largest of which are Wakool River, Niemur River, Colligen Creek, Yarrein Creek and Merran Creek. Forms part of the Riverine Plain. River lengths are Murray 487 km and Edward 356 km. The floodplain of the Murray varies in width from about 1 km near Echuca to about 20 km near Cohuna. The floodplain of the Edward is generally less than 1 km wide, except in the Werai Forest area, where the combined floodplain of the Edward and two of its anabranches is more than 10 km wide. Several anabranches, in particular the Wakool River, have larger floodplains than the Edward. Total floodplain area is 3482 km^2. Section 4 lies within Nix and Kalma's (1982) climatic subregion B11a, which has higher temperatures, greater solar radiation and, in particular, lower rainfall than the B12 classification of Sections 1 to 3. Mean annual rainfall is 300–400 mm.

Section 5

Floodplain of the Murray from 11 km downstream of Wakool Junction to the Darling Junction. The Murrumbidgee River joins the Murray within this section. Forms part of the Mallee Zone. River length is 448 km. The floodplain is broad, generally 5–12 km wide, but narrowing at Mildura and Wentworth to 1–3 km, with a total floodplain area of 1568 km^2. The climate is similar to Section 4, forming part of Nix and Kalma's (1982) climatic subregion B11a. Mean annual rainfall is 250–300 mm.

Section 6

Floodplain of the Murray from the Darling Junction to 22 km downstream of Loxton. Forms part of the Mallee Zone. River length is 358 km, the floodplain is broad, generally 5–10 km wide, and the total floodplain area is 1515 km^2. The climate is hot and dry, corresponding to Nix and Kalma's (1982) climatic subregion B11b. Mean annual rainfall is around 250 mm.

Section 7

Floodplain of the Murray from 22 km downstream of Loxton to Mannum. Forms part of the Mallee Zone. River length is 316 km. The river flows through a narrow valley, 30–40 m deep, and the floodplain is generally less than 2 km wide, with a total floodplain area of 416 km^2. Within Section 7 there is a transition from Nix and Kalma's (1982) climatic subregion B11b to subregion B11c, which is cooler, wetter and has a more pronounced rainfall seasonality, higher in winter and lower in summer. Mean annual rainfall is 200–300 mm.

Section 8

Floodplain of the Murray from Mannum to 2 km downstream of Wellington, at the head of Lake Alexandrina. Forms part of the Mallee Zone. River length is 76 km, the floodplain is generally less than 2 km wide, with a total floodplain area of 105 km^2. Forms part of Nix and Kalma's (1982) climatic subregion B11c. Mean annual rainfall is 300–350 mm.

Methods

Field survey

Sites were chosen subjectively to provide a geographically diverse coverage of each river section. 112 sites were visited on the floodplains of the Murray and Edward Rivers and their anabranches between Hume Dam and Lake Alexandrina, with 100 sites surveyed 8 September – 23 November 1987, and 12 sites surveyed 26 January – 6 February 1988.

Vegetation data were collected from one or more sample plots at each site, for a total of 335 plots. Sampling intensity was usually 1–6 plots per site, except for three sites of particular interest in South Australia (Lock 2, Dishers Creek Evaporation Basin and Murtho Forest), where 12–15 plots were sampled. The plots sampled different habitats or vegetation types at each site. Habitats across the floodplain were sampled, including rises within the floodplain above flood levels, but excluding inundated areas (permanent wetlands) and cleared areas. Time constraints did not allow sampling of all habitats at all sites (where this was attempted, for example, in the complex floodplain at Murtho Forest, 12 plots were needed). Usually only one plot was sampled per habitat per site, but three replicate plots were sampled per habitat in brief investigations of salt-affected vegetation at Dishers Creek Evaporation Basin, and vegetation under different flooding regimes upstream and downstream of Lock 2.

Each plot was 400 m^2 in area, measuring either 20 m X 20 m or, in narrow, elongated habitats such as riverbanks, 40 m X 10 m. Vegetation structure was recorded by estimating the average height and foliage cover of each vegetation layer. The vascular plant species growing within or overhanging the plot were identified and the cover/abundance of each species was recorded on a scale of 1 to 6 (1 = few plants, cover <5%; 2 = many plants, cover <5%; 3 = cover 5–24%; 4 = cover 25–49%; 5 = cover 50–74%; 6 = cover 75–100%). Species identifications were updated in 2011 to take account of nomenclatural changes since the original survey. This included some re-examination of specimens collected during the survey.

The condition of the eucalypt trees was assessed by counting the number of trees in or overhanging the plot under three categories: healthy (less than 40% of the crown dead), unhealthy (40% or more of the crown dead) or dead (not including stumps). Where necessary, additional trees adjacent to the plot were counted in order to sample at least 10 trees.

Regeneration of eucalypt species was assessed by counting the number of seedlings and saplings per plot in each of three classes: <1 m tall, 1–4 m tall, and >4 m tall. Coppice regeneration, seedlings under 5 cm high, and saplings with a diameter at breast height of 20 cm or more were not included in the counts. Regenerants included in the counts varied greatly in height, from 5 cm to about 16 m.

An index of grazing intensity was calculated for each plot by randomly laying a 20 m tape across the plot and counting the number of grazing animal droppings that touched the tape. For species that produce droppings in clusters, each cluster was counted as a single dropping. Additional grazing species for which there was evidence within the plot but not along the tape, were included in the count with an arbitrary value of 0.5 droppings.

Data analysis

The 335 plots were classified into plant communities based on the species composition and abundance data. Some pairs or groups of species were not consistently distinguished in the plots and were thus combined for the analysis (Appendix 2). Because of the large size of the data set, the classification was carried out in two stages. An initial non-hierarchical classification was performed by composite clustering (Gauch 1980), using the computer program COMPCLUS (Gauch 1979). This clustered the plots into 78 groups. A hierarchical classification of the 78 groups was then carried out by two-way indicator species analysis (Gauch and Whittaker 1981), using the program TWINSPAN (Hill 1979a). Relationships among the 78 COMPCLUS groups were further examined by the ordination technique of detrended correspondence analysis (Hill and Gauch 1980), using the program DECORANA (Hill 1979b).

The COMPCLUS groups within each TWINSPAN grouping were assessed subjectively. They were retained in the final classification if they reflected an obvious vegetation difference, or combined if the difference was considered minor. A few plots appeared to have been misclassified and were reassigned subjectively to other groups. One unusual plot was excluded from the analysis.

Analyses were also carried out on some of the data using the SPC for Excel statistics package (BPI Consulting LLC, Cypress, Texas) and the PATN pattern analysis package (Blatant Fabrications Pty Ltd, Carlton, Tasmania).

Vegetation mapping

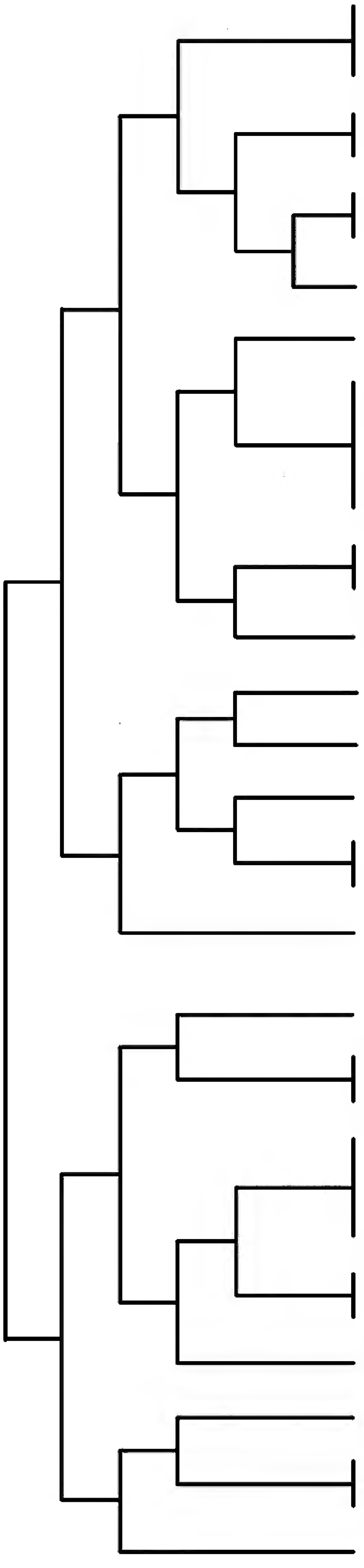
The floodplain vegetation of the survey area was mapped by other researchers independently but in parallel with the floristic survey (Margules and Partners *et al.* 1990). The mapping was done from air photos taken at various dates between 1965 and 1985. The map units were based on vegetation structure and condition rather than the floristic classification reported here. The results of the mapping are not included in this paper, but are available from the Murray-Darling Basin Authority as geographic information system layers.

Results and Discussion

Vegetation zones

The vegetation of the River Murray floodplain is dominated by just two tree species: River Red Gum *Eucalyptus camaldulensis* on the river banks and in low-lying areas, and Black Box *Eucalyptus largiflorens* in the less frequently flooded parts of the floodplain. There is a natural and well-known division of the floodplain into a River Red Gum zone and a Black Box zone. Historically, River Red Gum communities have received more regular flooding (45 to 90 flood years per century) than Black Box communities (10 to 50 flood years per century) (Roberts 2004).

A third vegetation zone consists of the occasional rises within the floodplain. These rises are rarely if ever flooded and support non-floodplain vegetation similar to that found on similar soils outside the floodplain, namely woodlands of



		Sp	Ex	Cd	Sections
36	*Callitris glaucophylla*	27	63	4	3
35	*Eucalyptus melliodora*	32	60	3	1-3
34	*Eucalyptus microcarpa*	37	58	3	2-3
16	**Salix x rubens*	32	59	0	1-3
4	*E.c.-Poa-Hemarthria*	33	56	0	1-2
19	*Lachnagrostis-*Cynodon*	25	54	0	2
14	*E.c.-*Bromus-Austrodanthonia*	29	58	2	4
13	*E.c.-*Bromus-*Vulpia*	29	63	0	1-4
3	*E.c.-Poa-Lachnagrostis*	37	45	0	1-4
10	*E.c.-Austrodanthonia*	35	48	1	2-4
6	*E.c.-Paspalidium-Senecio*	31	44	1	2-4
5	*E.c.-Carex*	35	44	1	3-4
2	*E.c.-Eleocharis-Wahlenbergia*	33	31	0	3-4
22	*E.l.-Eleocharis*	29	37	0	4
1	*E.c.-Eleocharis-Pseudoraphis*	14	18	0	1-6
20	*Pseudoraphis-Eleocharis*	10	16	0	3-4
21	*Centipeda-Polygonum*	25	36	0	2-5
11	*E.c.-E.l.*	25	36	5	4-5
7	*E.c.-Paspalidium-*Cynodon*	30	37	5	4-7
8	*E.c.-Cyperus*	24	35	3	6-7
9	*E.c.-Phragmites*	19	40	2	7-8
15	*E.c.-*Cynodon*	35	59	7	7-8
17	**Salix babylonica*	25	49	0	1-8
25	*E.l.-Melaleuca-Allocasuarina*	21	45	14	4
23	*E.l.-Muehlenbeckia-Chenopodium*	26	32	17	4-6
29	*Chenopodium-Muehlenbeckia*	30	22	28	4-6
26	*E.l.-Melaleuca-Atriplex*	26	34	30	6
24	*E.l.-Muehlenbeckia-Atriplex*	22	34	22	6-7
30	*Muehlenbeckia-Tecticornia*	26	38	28	6-7
33	*Sporobolus-Atriplex*	14	48	19	6-7
12	*E.c.-Muehlenbeckia*	27	37	10	5-7
18	*Callistemon-Muehlenbeckia*	31	44	20	7
37	*Dodonaea-Callitris*	24	36	5	5-6
28	*E.l.-Atriplex rhagodioides*	23	23	24	6
27	*E.l.-Atriplex nummularia*	32	32	29	5-6
31	*Atriplex-Tecticornia*	22	26	25	5-6
32	*Tecticornia* spp.	12	36	37	4-8

KEY:

Sp	no. species per plot	***E.c.***	*Eucalyptus camaldulensis*
Ex	% exotic species per plot	***E.l.***	*Eucalyptus largiflorens*
Cd	% chenopod species per plot		

Fig. 2. TWINSPAN classification of the plant communities of the Murray floodplain.

Grey Box *Eucalyptus microcarpa*, Yellow Box *Eucalyptus melliodora* and cypress pine *Callitris* species. A fourth zone, the permanent wetlands, was the subject of Pressey (1986) and was not included in the present study.

River Red Gum has the widest natural distribution of all eucalypts, growing along inland watercourses right across Australia and in some non-floodplain situations in South Australia and Victoria (Beadle 1981). River Red Gums line the Murray throughout the survey area except for Section 8, where they have been largely replaced by the exotic Weeping Willow *Salix babylonica*. In the flood-prone Barmah-Millewa forests of Section 3, River Red Gums form tall, dense forests, some exceeding 45 m in height at maturity, and cover almost the entire floodplain, which is some 25 km wide. By contrast, in the semi-arid reaches, River Red Gums are restricted to the immediate vicinity of the river and its associated channels and billabongs. They occur here as woodlands rather than forests, often in a strip only one or two trees wide.

The understorey in the River Red Gum zone is predominantly herbaceous, with a mix of perennials, annuals and post-flooding ephemerals. Prominent, widespread species include Warrego Summer-grass *Paspalidium jubiflorum*, Moira Grass *Pseudoraphis spinescens*, Common Spike-rush *Eleocharis acuta*, Spiny Sedge *Cyperus gymnocaulos*, Common Sneezeweed *Centipeda cunninghamii*, Cotton Fireweed *Senecio quadridentatus* and River Bluebell *Wahlenbergia fluminalis*.

Black Box is less widespread in Australia than River Red Gum, being restricted to inland floodplains of the south-east (Beadle 1981). It is also less widespread along the Murray, where it occurs in the semi-arid reaches from about the upper junction of the Edward River downstream to Mannum. Black Box is rare in Section 3, occurring only in small stands on the outer margin of the floodplain (Chesterfield *et al.* 1984), whereas in Section 6 the Black Box zone covers most of the floodplain.

The Black Box communities generally have a lower, more open tree layer than the River Red Gum communities, forming woodlands rather than forests. They also have a shrubbier understorey. In addition, the Black Box zone includes extensive shrublands, lacking a tree layer but otherwise similar in floristic composition to the adjacent Black Box woodlands. The principal shrub species are Lignum *Muehlenbeckia florulent*a, Dryland Tea-tree *Melaleuca lanceolata* and various chenopods – Nitre Goosefoot *Chenopodium nitrariaceu*m, Silver Saltbush *Atriplex rhagodioides*, Old-man Saltbush *Atriplex nummularia*, Bladder Saltbush *Atriplex vesicaria* and Desert Glasswort *Tecticornia triandra*.

Plant Communities

The COMPCLUS and TWINSPAN analyses distinguished 37 plant communities described in Appendix 1, grouped into the three vegetation zones. As a one-off sampling, the survey did not encompass the dynamics of the understorey composition, especially the effects of ephemerals. These effects are most apparent in the changing nature of the vegetation in temporary wetlands at different stages of the flooding cycle. However, the classification presented here is a broad one and ephemerals are unlikely to have a major influence. This is borne out by observations during the survey that some River Red Gum plots had been recently flooded while others in similar situations had missed out on flooding, yet still grouped with the flooded plots in the analyses.

Floristic relationships among the communities, as indicated by the TWINSPAN analysis, are shown by a dendrogram (Fig. 2) and a two-way classification of communities and species (Appendix 2). The primary TWINSPAN division is between the River Red Gum and Black Box zones (Fig. 2). However, the *Eucalyptus largiflorens – Eleocharis* community groups with the River Red Gum communities, while the *Eucalyptus camaldulensis – Muehlenbeckia* community, and the related *Callistemon – Muehlenbeckia* shrubland, group with the Black Box communities. The communities of the rises do not separate as a group but are split between the River Red Gum and Black Box groupings. The communities of Riverine Plain rises (the *Callitris glaucophylla*, *Eucalyptus melliodora* and *Eucalyptus microcarpa* communities) show affinity with weedy River Red Gum communities because of the many weed species that they share. The *Dodonaea – Callitris* community of Mallee Zone rises shows more affinity with Black Box communities from the same zone.

Within the River Red Gum grouping, the major division is between Riverine Plain/Headwaters Zone communities of the upper Murray (Sections 1 to 4) and Mallee Zone communities of the lower Murray (Sections 5 to 8). The Riverine Plain/Headwaters Zone subgroup divides into the more weedy communities (including the communities of the Riverine Plain rises) and the less weedy ones. The less weedy communities further divide into frequently flooded and infrequently flooded communities. The frequently flooded communities include the tallest River Red Gum forests (the *Eucalyptus camaldulensis – Eleocharis – Pseudoraphis* community) and also herbaceous communities from sites where flooding is too frequent for tree growth (the *Pseudoraphis – Eleochari*s and *Centipeda – Polygonum* communities). The Mallee Zone subgroup consists of the *Salix babylonica* community and various *Eucalyptus camaldulensis* communities, the latter dividing into those typical of Section 5 and those typical of South Australia.

Within the Black Box grouping, the major division is between the communities of the outer floodplain (characterised by the perennial saltbushes, *Atriplex rhagodioides*, *Atriplex nummularia* and *Atriplex vesicaria*, occurring chiefly in Section 6) and those of the inner floodplain (characterised by Lignum *Muehlenbeckia florulenta*). The inner floodplain subgroup also includes the *Dodonaea – Callitris* community of the rises and the uncommon *Eucalyptus largiflorens – Melaleuca* communities, which are also associated with higher ground. The outer floodplain subgroup includes the samphire *Tecticornia* species communities of the most saline sites.

In both Black Box subgroups there is a division between the South Australian communities (e.g. the *Eucalyptus largiflorens – Muehlenbeckia – Atriplex* and *Eucalyptus largiflorens – Atriplex rhagodioides* communities) and their counterparts across the border in New South Wales and Victoria (the *Eucalyptus largiflorens – Muehlenbeckia – Chenopodium* and *Eucalyptus largiflorens – Atriplex nummularia* communities). The reason for this division is unclear. It contrasts with the major division among the River Red Gum communities, which is between the Mallee Zone and the Riverine Plain/Headwaters Zone, which are more obviously different environments.

An alternative representation of floristic relationships is provided by the DECORANA ordination (Fig. 3). The four main groups of the TWINSPAN classification can be distinguished in the ordination, arranged along Axis 1 in a sequence: Riverine Plain/Headwaters Zone River Red Gum communities, Mallee Zone River Red Gum communities, inner Black Box zone communities, and outer Black Box zone communities. Axis 2 separates communities within the main groups.

The axes in Figure 3 have been derived entirely from the floristic data but also reflect environmental gradients. Axis 1, the principal axis, corresponds closely with the distribution of chenopods. There is a highly significant correlation between a community's Axis 1 score and the mean proportion of chenopod species per plot in that community (r = 0.91, P<<0.001, arcsine transformation of proportions), accounting for 84% of the variation in Axis 1 scores. Most, perhaps all, chenopods are salt-tolerant (Waisel 1972), suggesting that Axis 1 is primarily a salinity gradient, reflecting the more saline conditions in the Mallee Zone compared with the Riverine Plain, and the increase in salinity across the floodplain (since less frequent flooding means less frequent flushing of accumulated salt). The strong relationship between floristics and salinity levels emphasises the major impact that increasing salinisation has on the floodplain flora.

Interpretation of Axis 2 is more difficult. It appears to represent a combination of floristic variation associated with changes in flooding frequency, climate and other factors.

On a local scale, there is typically a marked change in vegetation across the floodplain, and often a mosaic of different communities. For example, Figure 4 is a diagrammatic representation of the vegetation pattern at one

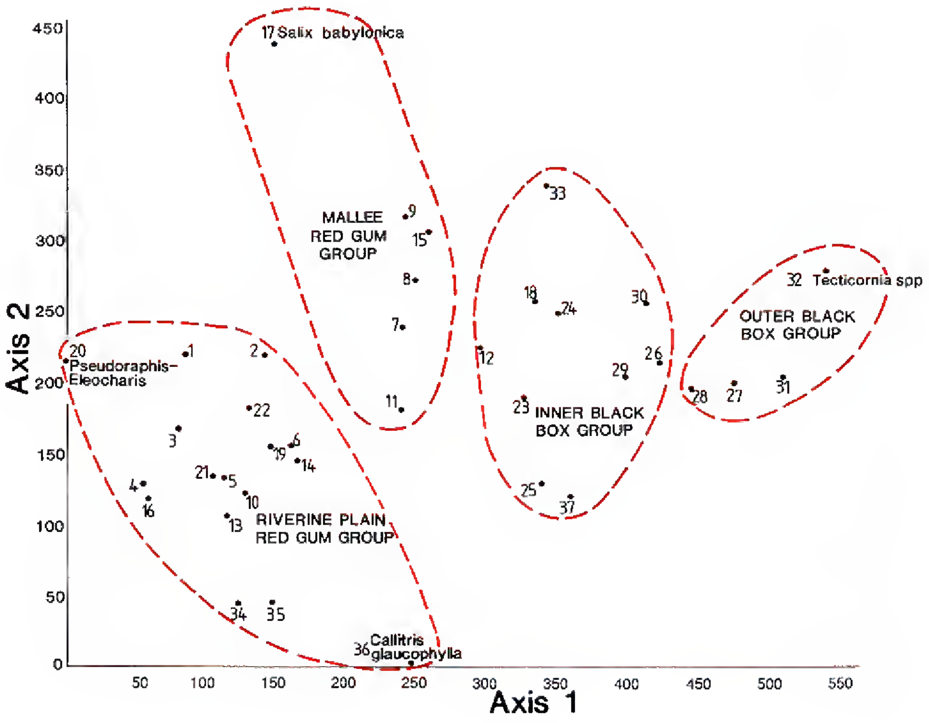


Fig. 3. DECORANA ordination of the plant communities of the Murray floodplain. Communities numbered as in Appendix 1.

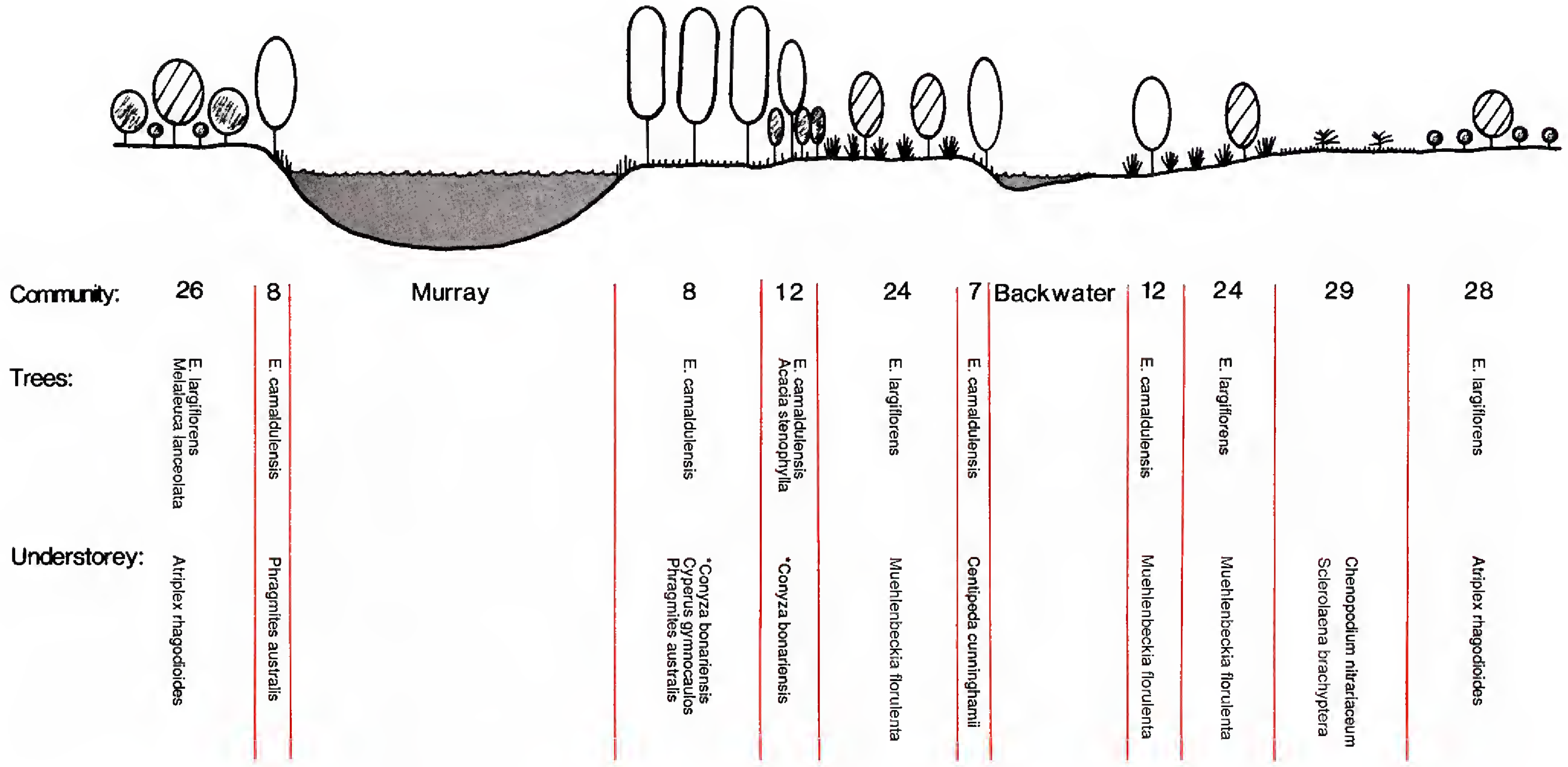


Fig. 4. Vegetation change across the floodplain near Murtho in Section 6.

locality in the Murtho area, north of Renmark, in Section 6, where 12 plots were sampled. The changes portrayed occur over a distance of about 1 km. Such complex patterns are a result of the variation in landform, soil and hydrology across the floodplain, which is determined chiefly by fluvial processes, both present and past (van der Sommen 1987).

Landform is especially important, since minor differences have a major effect on the frequency and duration of flooding. This is illustrated by vegetation patterns on the riverbank adjacent to the water. Typically, there is a series of narrow bands of different plant species at different heights above the water, i.e. different flooding regimes. For example, at a drying billabong on Ulupna Island in Section 2, there was a sequence from the water's edge of *Amphibromus fluitans*, *Lachnagrostis filiformis*, *Eleocharis* species, *Carex tereticaulis* and *Bromus diandrus* over a distance of about 10 m and a change in elevation of about 1 m. Such sequences show how closely linked are local vegetation patterns to flooding patterns.

Plant species

A total of 499 plant species, subspecies and varieties were recorded in the 335 survey plots, of which 316 (63%) were native and 183 (37%) were exotic (Appendix 3). Among the native species, the dominant plant families, in decreasing order, were the Asteraceae (daisies), Chenopodiaceae (chenopods), Poaceae (grasses), Cyperaceae (sedges) and Fabaceae (wattles and peas) (Table 1). Among the exotic species, the dominant families were the Poaceae, Asteraceae, Fabaceae and Brassicaceae (cress family). The Myrtaceae (eucalypt family), although represented by relatively few species, all native, were the dominant trees.

The prominence of River Red Gum *Eucalyptus camaldulensis* throughout the survey area gives a misleading impression of uniformity in the vegetation. Most species have a far more restricted distribution, reflecting the changes in climate, geomorphology and soils along the river (Appendix 3). Apart from *Eucalyptus camaldulensis*, only 12 species (five native and seven exotic, predominantly Asteraceae and Poaceae) were recorded in every river section (Appendix 3). The changing floristic composition of the vegetation along the river is reflected in the restricted distribution of most plant communities (Fig. 2).

Table 1. Major plant families of the floodplain flora
Taxa include species, subspecies and varieties

Family	**Number of taxa recorded**		
	Native	Exotic	Total
Poaceae (grasses)	38	44	82
Asteraceae (daisies)	46	30	76
Chenopodiaceae (chenopods)	42	2	44
Fabaceae (wattles and peas)	14	23	37
Cyperaceae (sedges)	17	2	19
Brassicaceae (cress family)	3	12	15
Polygonaceae (dock family)	10	4	14
Ranunculaceae (buttercup family)	8	3	11
Juncaceae (rushes)	8	1	9
Other families	130	62	192
Total	**316**	**183**	**499**

The TWINSPAN analysis provided a two-way classification of species and communities (Appendix 2) for 176 'species' that are relatively common, at least in certain communities (including several pairs or groups of species not consistently distinguished in the field and thus combined for analysis). The species divide into four major groups: 69 species (39%) closely associated with the River Red Gum zone; 29 (16%) found in both River Red Gum and Black Box zones but more common in the former; 22 (13%) equally common in both River Red Gum and Black Box zones; and 56 (32%) associated mainly with the Black Box zone, although many also occur in River Red Gum communities, especially those of the Mallee Zone.

The Asteraceae and Poaceae are well represented in all four groups. However, other major families tend to be associated with either the River Red Gum or the Black Box zone. The Cyperaceae, Fabaceae and Juncaceae occur chiefly in the herbaceous understorey of the River Red Gum zone, as do most of the Polygonaceae except Lignum *Muehlenbeckia florulenta*, which is a common shrub of the Black Box zone. The characteristic family of the Black Box zone is the Chenopodiaceae, which is co-dominant there with the Asteraceae and Poaceae. The shrubby nature of the Black Box zone understorey is chiefly due to the abundance of chenopods and Lignum.

The prominence of the salt-tolerant Chenopodiaceae is indicative of the more saline conditions in the Black Box zone compared with the River Red Gum zone. The results of the DECORANA ordination (Fig. 3) suggest that salinity is the most important factor responsible for the floristic differences between the two zones, although flooding frequency may be the more important factor for the two tree species.

The communities with the lowest number of species per plot were Communities 1 and 20 in the River Red Gum zone, and Communities 32 and 33 in the Black Box zone (Fig. 2, Appendix 1). Communities 1 (*Eucalyptus camaldulensis – Eleocharis acuta – Pseudoraphis spinescens* open-forest) and 20 (*Pseudoraphis spinescens – Eleocharis acuta* herbland) are both subject to frequent and prolonged flooding, which may limit the number of species capable of surviving. Communities 32 and 33 are associated with high levels of disturbance, Community 32 (*Tecticornia pergranulata – Tecticornia indica* shrubland) occurring in highly saline sites and Community 33 (*Sporobolus mitchellii – Atriplex leptocarpa* grassland) in overgrazed sites.

The communities with the highest number of species per plot were Communities 3 (*Eucalyptus camaldulensis – Poa labillardierei – Lachnagrostis filiformis* open-forest), 5 (*Eucalyptus camaldulensis – Carex tereticaulis* open-forest) and 10 (*Eucalyptus camaldulensis – Austrodanthonia caespitosa* woodland) in the River Red Gum zone, and

Community 34 (*Eucalyptus microcarpa* open-forest) in the floodplain rises zone (Fig. 2, Appendix 1). The three River Red Gum communities had high numbers of both native and exotic species. The Grey Box (*Eucalyptus microcarpa*) community was less rich in native species, but had the highest number of exotic species per plot of any community.

Weed invasion

37% of all plant species recorded were exotic (183 of 499 species). Weeds were common throughout the survey area, but were most prevalent in the wetter climates at the upper and lower ends of the river, in Sections 1, 2 and 8. The median number of exotic species per plot exceeded or equalled the number of native species in these three sections of the river, whereas native species outnumbered exotic species in the other river sections (Fig. 5). The highest numbers of native species and lowest numbers of exotic species per plot were recorded in Sections 5 and 6 (Fig. 5). Differences between river sections were statistically significant (Kruskal Wallis test). In particular, the number of native species per plot was significantly higher in Sections 5 and 6 than in Section 8 ($P = 0.02$), and the number of exotic species per plot was significantly higher in Sections 1, 2 and 8 than in Sections 5, 6 and 7 ($P << 0.001$).

Differences were also evident between the vegetation zones (Fig. 6). There was no significant difference between the three zones in the number of native species per plot, but the number of exotic species per plot was significantly lower in the Black Box zone than in the River Red Gum zone and the floodplain rises (Kruskal Wallis test, $P << 0.001$). Exotic species strongly influenced the community classification and were the dominant overstorey species in two communities (Communities 16 and 17, dominated by willows *Salix* species). Exotic species dominated the understorey in another eight communities (Fig. 2). These communities included one South Australian River Red Gum community (Community 15), three Riverine Plain River Red Gum communities (Communities 4, 13 and 14), three communities of Riverine Plain rises (Communities 34, 35 and 36), and one grassland community colonising point bar deposits (beaches) on the Riverine Plain (Community 19).

The high level of weed invasion reflects the history of intensive disturbance along the Murray since the 1830s (Frith and Sawer 1974) and the susceptibility of floodplain vegetation to weed invasion (de Waal *et al.* 1994, Hood and Naiman 2000). Recent studies have indicated that reduced flooding as a result of river regulation and water extraction has favoured exotic species (Stokes *et al.* 2010, Catford *et al.* 2011). However, other disturbance factors, including agricultural activities, urban development, recreational activities and logging, have also promoted weed invasion.

Eucalypt health

The overall condition of eucalypt trees along the Murray during the 1987–88 survey was assessed as 68% healthy, 21% unhealthy (at least 40% of the crown dead) and 11% dead (not including stumps), based on a sample of 3649 trees. The species involved were predominantly River Red Gum (*Eucalyptus camaldulensis*) and Black Box (*Eucalyptus largiflorens*), with a few Yellow Box (*Eucalyptus melliodora*) and Grey Box (*Eucalyptus microcarpa*) on the rises.

Eucalypt health was best in Sections 1 and 2, and became steadily worse downstream, being poorest in Sections 6, 7 and 8 below the Darling Junction, particularly in terms of the high proportion of dead trees in these sections (Fig. 7). The relationship between eucalypt health and river section was highly significant (chi square test, $P << 0.001$). The condition

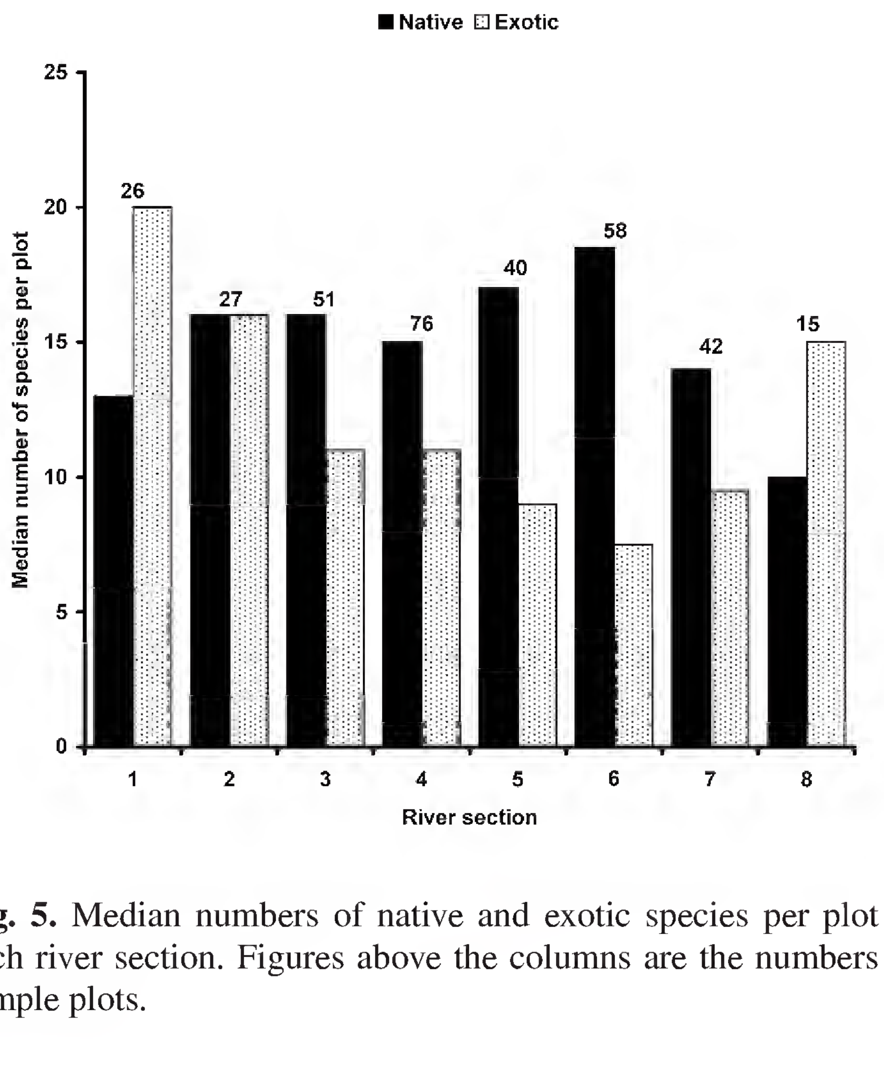


Fig. 5. Median numbers of native and exotic species per plot in each river section. Figures above the columns are the numbers of sample plots.

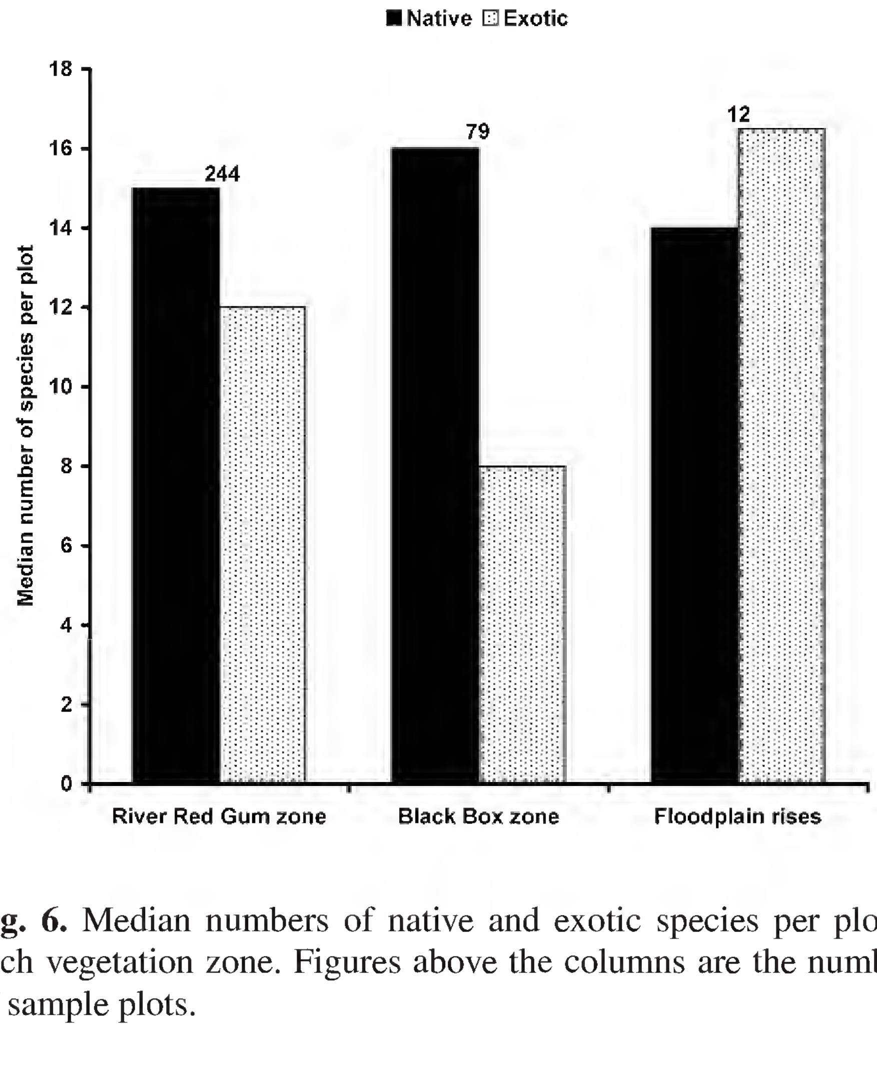


Fig. 6. Median numbers of native and exotic species per plot in each vegetation zone. Figures above the columns are the numbers of sample plots.

of eucalypt trees below the Darling Junction was assessed as 60% healthy, 18% unhealthy and 22% dead (sample of 1053 trees). By comparison, 84% of the trees in Sections 1 and 2 were healthy, 14% unhealthy and only 2% dead (sample of 559 trees). The many dead trees along the river in South Australia in the 1980s were also noted by Thompson (1986).

Obvious causes of tree death in Sections 6, 7 and 8 were soil salinisation (particularly in Sections 6 and 7, involving both River Red Gum and Black Box) and raised river levels from construction of weirs, resulting in permanent inundation of low-lying areas that were formerly temporary wetlands (particularly in Sections 7 and 8, River Red Gum only).

While some low-lying sites have become wetter as a result of river regulation, the Murray floodplain in general has become drier through reduced flooding because of the high level of water extraction, mainly for irrigation, throughout the Murray-Darling Basin. The reduction in flooding frequency has been greatest in the lower Murray, below the Darling Junction, corresponding to the part of the floodplain with the poorest tree health in 1987–88. Flows in the lower Murray have been approximately halved, and the frequency and duration of small, medium and large floods have all been significantly reduced (Walker and Thoms 1993, Maheshwari *et al.* 1995, Dyer 2002, Roberts 2004, CSIRO 2008). Reduced flooding means not only less water for the trees but also increasing soil salinisation because of less flushing of accumulated salt from the saline Mallee Zone floodplain. The situation was exacerbated during the prolonged Millenium Drought after our survey, when overbank flows were largely absent along the lower Murray between 1994 and 2010 (Holland *et al.* 2013).

Severe declines in eucalypt health were reported during the Millenium Drought. Smith and Kenny (2005) reported that 49% of River Red Gum trees and 62% of Black Box trees on the Murray floodplain in South Australia were unhealthy or dead. Brett Lane and Associates (2005) reported that the proportion of stressed trees in the Chowilla anabranch region of South Australia increased from 54% in 2002 to 89% in 2004, with River Red Gum trees most affected. The Murray-Darling Basin Commission (2003) reported that about 80% of River Red Gum trees on the lower Murray were stressed to some degree, with 20 to 30% severely stressed. Eucalypt health deteriorated further as the drought continued between 2003 and 2009. Cunningham *et al.* (2009) assessed that 72% of River Red Gum stands, and 92% of Black Box stands along the river were in a stressed condition in 2009, and that the extent of stressed stands had been 66% lower in 2003. The situation was worse in the Mallee Zone than in the Riverine Plain. Following the breaking of the drought with a major flood over the summer of 2010–11, a significant improvement in the condition of both River Red Gum and Black Box trees was reported at several sites along the Murray in 2012 (Bennetts and Jolly 2012, Henderson *et al.* 2012a, 2012b).

Another factor that can affect River Red Gum condition is the Gum Leaf Skeletoniser *Uraba lugens*, a moth whose larvae feed on eucalypt foliage, particularly River Red Gums. The larvae seldom kill the trees but may cause severe defoliation over large areas (for example, some 40 000 ha of River Red Gum forest along the Murray and Goulburn Rivers in 1975) and drastically check growth (Harris 1986, Harris *et al.* 1977). Major outbreaks occur in roughly ten-year cycles, when the forest is almost completely defoliated. Moth populations then crash and the trees recover rapidly. There was evidence of Gum Leaf Skeletoniser activity at some sites during our 1987–88 survey, for example, Nyah State Forest in Section 4, but this was limited in extent and is likely to be a negligible influence on the tree health measures in Figure 7.

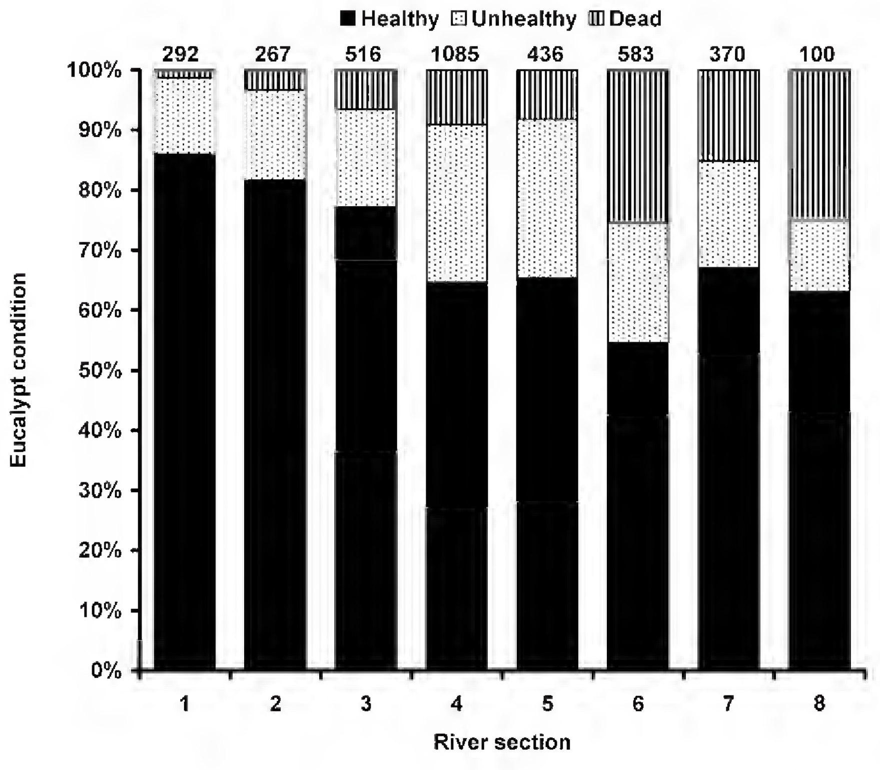


Fig. 7. Condition of eucalypt trees in each river section (all species combined). Figures above the columns are sample sizes.

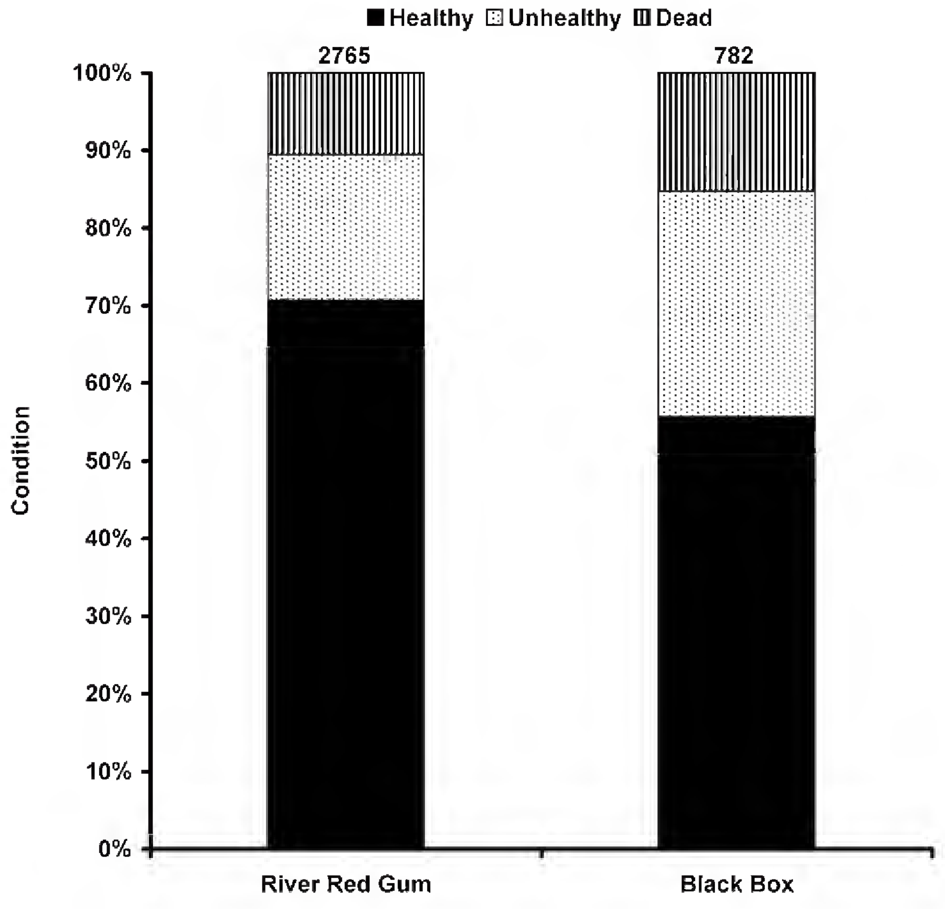


Fig. 8. Comparison of the condition of River Red Gum and Black Box trees along the Murray. Figures above the columns are sample sizes.

The condition of Black Box trees along the Murray was significantly worse than the condition of River Red Gum trees during our 1987–88 survey (Fig. 8, chi square test, *P* << 0.001). Overall, 71% of River Red Gum trees were healthy, 19% unhealthy and 10% dead (sample of 2765 trees), whereas only 56% of Black Box trees were healthy, 29% unhealthy and 15% dead (sample of 782 trees). Subsequent studies by Smith and Kenny (2005) and Cunningham *et al.* (2009) during the Millennium Drought also reported Black Box in worse condition than River Red Gum.

Black Box health has been studied intensively in the Chowilla anabranch region in Section 6 in South Australia (Eldridge *et al.* 1993, Walker *et al.* 1996, Jolly 1996, Jolly *et al.* 1993, 1996, Taylor *et al.* 1996, Overton *et al.* 2006), where there has been extensive and increasing dieback of Black Box. Salinisation of floodplain soils as a result of the hydrological management of the River Murray has been identified as the primary cause of the dieback. The higher river level after construction of Lock 6 has caused groundwater levels beneath the floodplains to rise, while water extractions upstream have reduced flooding. The higher water tables have resulted in increased soil salinity, while the decreased incidence of overbank floods has reduced leaching of salt from the floodplain soils. These combined processes have led to the disturbance of the natural salt balance in the soil profile, leading to salt accumulation and tree deaths. It should be noted, however, that in the upper Murray, where the groundwater is predominantly fresh, dieback of floodplain trees is associated with falling groundwater levels rather than rising ones (Cunningham *et al.* 2011).

Eucalypt regeneration

The overall density of eucalypt regeneration in the survey area during the 1987–88 survey was 467 regenerants per ha, based on 303 sample plots in eucalypt vegetation (including all regenerants over 5 cm high and up to 20 cm diameter at breast height). River Red Gum regeneration was much more frequent and denser than Black Box regeneration. It was evident in 69% of the 248 River Red Gum plots but only 29% of the 76 Black Box plots, a significant difference (chi square test, *P* << 0.001). The overall density of Black Box regenerants (124 per ha) was less than a quarter of the density of River Red Gum regenerants (525 per ha).

A similar difference between the two species has been reported by George *et al.* (2005), in a population viability analysis of floodplain eucalypts at Banrock Station in Section 7. The Black Box population at this site appears to lack sufficient regeneration to compensate for adult mortality, implying that the population is unlikely to survive in the long term, whereas the River Red Gum population has a better balance of age classes and a better chance of survival.

Eucalypt regeneration also varied significantly with river section (Fig. 9, chi square test, *P* << 0.01). Like the health of the trees themselves, regeneration was worse in the lower Murray below the Darling Junction, in Sections 6, 7 and 8, in terms of both the percentage of plots with regeneration (35% of plots below the Darling versus 77% of plots upstream; Fig. 9) and the density of regeneration (115 regenerants per ha below the Darling versus 635 per ha upstream; Fig. 10). The poor eucalypt regeneration in the lower Murray is due to a combination of factors, including reduced flooding, increasing salinisation, overgrazing and less post-logging regeneration.

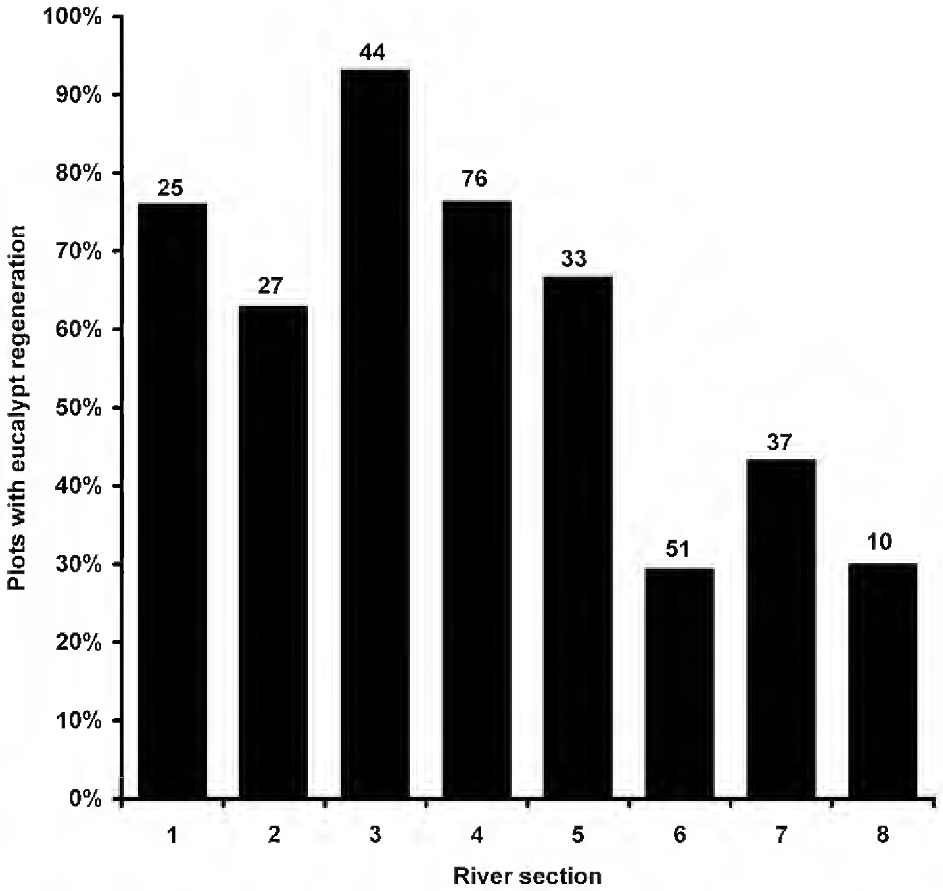


Fig. 9. Frequency of eucalypt regeneration in each river section (all species combined). Figures above the columns are the numbers of sample plots.

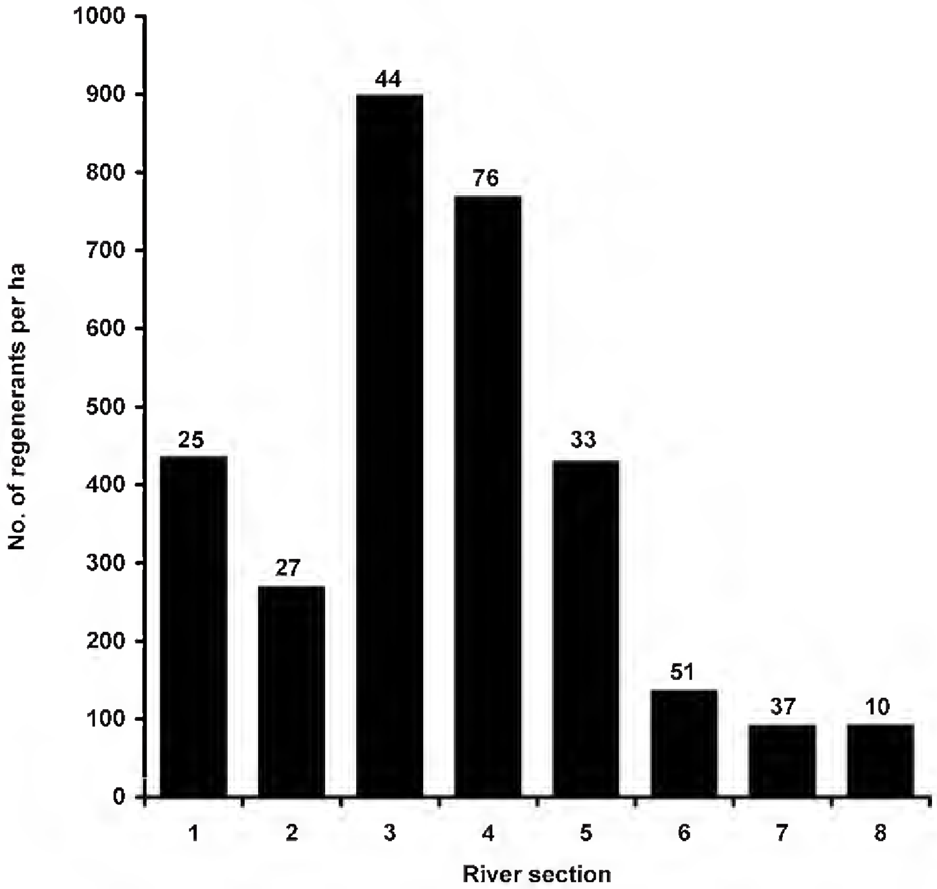


Fig. 10. Density of eucalypt regeneration in each river section (all species combined). Figures above the columns are the numbers of sample plots.

Natural regeneration of floodplain eucalypts is episodic (George *et al.* 2005) and large-scale regeneration occurs after major floods (Treloar 1959). Moisture is one of the most critical factors controlling the germination and survival of River Red Gum seedlings, with optimal conditions being winter and spring flooding followed by a mild summer (Jacobs 1955, Dexter 1967, 1978). Regeneration of Black Box is also promoted by flooding, with seedlings typically becoming established in a narrow belt at the maximum extent of the flood (Cunningham *et al.* 1981).

Salinisation also impacts on eucalypt regeneration. During the 1987–88 survey, 13 plots were sampled in vegetation where there had been extensive death of eucalypts from salinisation. All were in Sections 6 and 7, constituting 15% of the 88 plots in eucalypt vegetation in these two river sections. The density of eucalypt regeneration in the 13 plots was low: a mean of 15 regenerants per ha compared with a mean of 135 per ha in the other 74 eucalypt plots in these two sections.

The poor and patchy nature of River Red Gum regeneration in South Australia in the 1980s was also noted by Thompson (1986), Venning (1984) and Kiddle (1987), who concluded that grazing was severely restricting regeneration. This conclusion was based on the observation that where regeneration occurs it is often in situations where there is some protection from grazing. Similar observations were made during the 1987–88 survey. Evidence of grazing animals in the survey plots included livestock (mainly sheep *Ovis aries* and cattle *Bos taurus*, occasionally horses *Equus caballus*), feral animals (mainly European Rabbits *Oryctolagus cuniculus*, occasionally pigs *Sus scrofa*) and native animals (mainly kangaroos, occasionally Emus *Dromaius novaehollandiae*). Kangaroo droppings were not identified to species, but general observations indicated that they were mainly Eastern Grey Kangaroos *Macropus giganteus* on the Riverine Plain and Western Grey Kangaroos *Macropus fuliginosus*, plus some Red Kangaroos *Macropus rufus*, in the Mallee Zone.

On the Murrumbidgee River floodplain, sheep and cattle grazing is known to have a strong negative impact on River Red Gum regeneration, depending on stocking rate (Robertson and Rowling 2000, Jansen and Robertson 2001). In Barmah State Forest in Section 3, Dexter (1967, 1978) found that grazing by cattle, kangaroos and rabbits had only a minor effect on River Red Gum regeneration during good years, but their impact could be substantial during drought years. Seedling establishment in Black Box is also known to be severely impacted by grazing (Chettle 1959, Treloar 1959, Duncan *et al.* 2007), especially as the leaves of Black Box appear to be more palatable than those of River Red Gum (Jacobs 1955).

Another factor involved in the paucity of eucalypt regeneration on the lower Murray floodplain is logging history. Logging promotes regeneration by opening out the canopy (Jacobs 1955, Dexter 1967). For example, Treloar (1959) reported that the survival rate for Black Box seedlings increased four to five fold if the overhanging canopy of the parent tree was trimmed. Logging, particularly of River Red Gums, has been an important industry along the Murray in New South Wales and Victoria, but less so in South Australia. There was evidence of logging (stumps in or near the plot) in 78% of the eucalypt plots in Sections 1 to 5, but only 26% of the plots in Sections 6 to 8 (Fig. 11). The higher intensity of logging in the upper and middle Murray has promoted more regeneration in these sections of the river.

Prolific River Red Gum regeneration was observed in some depressions within the River Red Gum zone. Regeneration was much more abundant (4065 regenerants per ha) in Community 21, *Centipeda cunninghamii – Polygonum plebeium* herbland, which is characteristic of such sites, than in any other community (Appendix 1). The importance of these depressions was also noted in a regeneration survey in South Australia (Kiddle 1987). These sites are subject to frequent flooding, both from river flows and from local rain. Seeds come from surrounding River Red Gums and there is extensive germination after flooding, although most of the seedlings are killed by subsequent flooding. Saplings only become established around the edges of the depressions.

Prolific River Red Gum regeneration was also observed on the edges of the extensive Moira Grass (*Pseudoraphis spinescens*) plains (Community 20, *Pseudoraphis spinescens – Eleocharis acuta* herbland) in Barmah State Forest in Section 3. In one sample plot near Hut Lake this regeneration averaged 11 m in height with a density of 7400 regenerants per ha (mixed ages), representing a young stand of Community 1, *Eucalyptus camaldulensis – Eleocharis acuta – Pseudoraphis spinescens* open-forest, colonizing the outer parts of a Moira Grass plain. There was an abrupt boundary between the regeneration and the remaining Moira Grass plain, from which River Red Gum trees and regeneration were almost entirely absent.

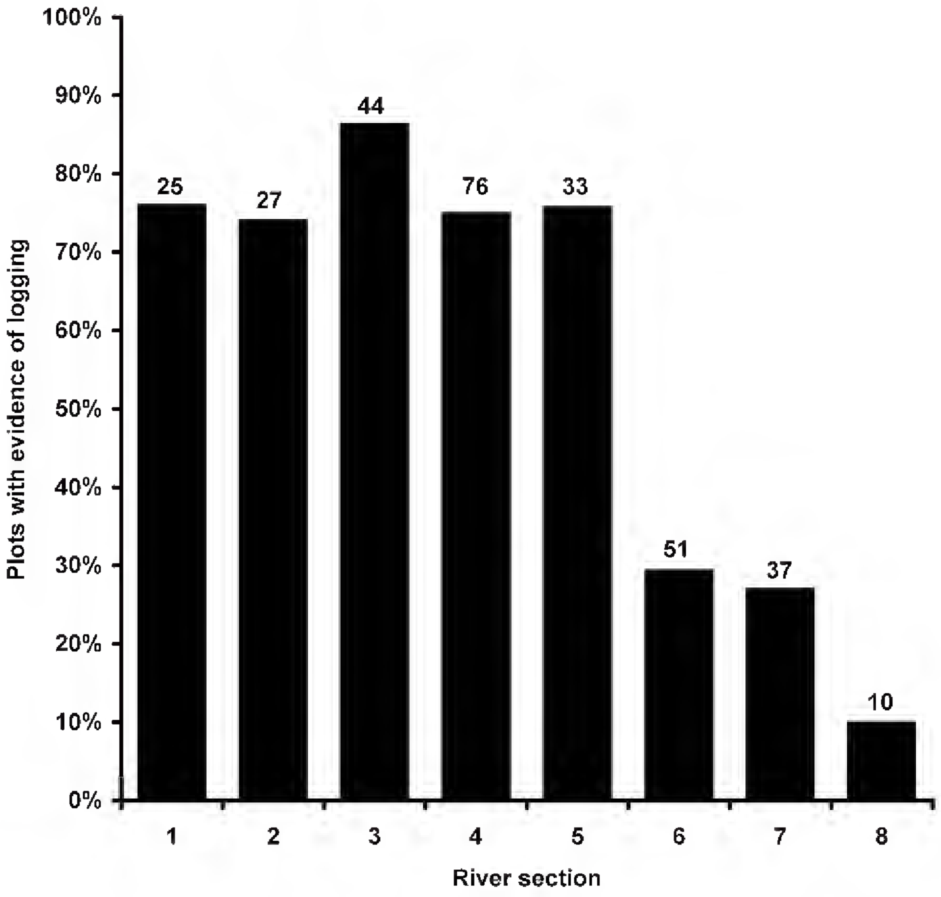


Fig. 11. Frequency of plots with evidence of logging (stumps in or near the plot) in each river section. Figures above the columns are the numbers of plots sampled.

Chesterfield (1986) estimated that this invasion of the Moira Grass plains by River Red Gums covered about 4% of the total area of Barmah State Forest in the 1980s. It appears to be a consequence of the reduced frequency of minor flooding since river regulation, allowing River Red Gums to become established where flooding was once too frequent and prolonged for them (Dexter *et al.* 1986, Bren 1992).

The changes to flood regimes in Section 3, and their effects on River Red Gum growth and regeneration, have been the subject of numerous studies (Dexter 1967, 1978, Dexter *et al.* 1986, Chesterfield 1986, Chesterfield *et al.* 1984, Bren 1988, 1992, Bren and Gibbs 1986). Major floods in this section have been little affected by river regulation but there has been a reduced frequency of minor flooding in winter and spring. This has been linked to the invasion of the Moira Grass plains by River Red Gums, but it has also meant less vigorous growth and regeneration of River Red Gums over large areas at slightly higher elevations.

Effects of weirs

Eleven weirs with locks (Locks 1 to 11) were constructed between Blanchetown and Mildura in the 1920s and 1930s, followed by construction of five barrages between the islands at the Murray mouth in the 1940s (Jacobs 1990). Hume Dam was also constructed in the 1920s and 1930s. The weirs and barrages are operated so that water levels upstream remain at or near a specified ‘normal pool level’ except during floods. Fluctuations in water level increase gradually upstream along the weir pools, reaching a maximum at the upper end of the weir pool, where the variability in water level is similar to natural conditions. From the Murray mouth to the top of the Lock 11 pool, some 92 km upstream of Mildura, the weir pools are continuous. As a result, water levels in this part of the river (Sections 6, 7 and 8, and the lower half of Section 5) are now generally higher and more stable than would have been the case under natural conditions. Between the Lock 11 pool and Hume Dam, the river is free-flowing and water levels fluctuate with variations in flow, except for weir pools at Euston (Lock 15), Torrumbarry (Lock 26) and Yarrawonga Weir on the Murray, and Stevens Weir on the Edward River.

The effects on floodplain vegetation of the more stable water levels in the lower Murray were investigated during the 1987–88 survey by comparing the vegetation immediately upstream (stable water levels) and downstream (fluctuating water levels) of Lock 2 near Taylorville in Section 7. Six plots were sampled upstream of the weir (three riverside plots and three on top of the bank) and six plots were sampled downstream (again, three riverside and three on top of the bank). All plots were 10 m by 40 m, with the long axis parallel to the river.

The mean number of native species recorded per plot downstream of the weir (15.7 ± s.e. 1.2) was significantly higher than the mean number upstream (11.0 ± s.e. 1.1) (two-factor ANOVA, P = 0.02, no significant difference between riverside and top of bank). The number of native species per plot upstream of the weir, where water levels are stable, was only about 70% of the number recorded per plot downstream of the weir, where water levels fluctuate. No significant differences were found for the number of exotic species recorded per plot.

There were also marked differences in the species composition of the floodplain vegetation upstream and downstream of the weir. In an agglomerative hierarchical classification of the 12 plots based on their plant species composition and cover/abundance values, using the Bray and Curtis association measure and the Flexible UPGMA classification technique (PATN program), the main division was between the six plots upstream and the six plots downstream (Fig. 12). Secondary divisions were between riverside plots and plots on top of the bank, although one upstream riverside plot grouped with the upstream top of the bank plots.

Upstream of the weir, the river was fringed by reedbeds of *Phragmites australis* and *Typha* species, which ended abruptly at the weir and were absent downstream. Behind the reedbeds and on top of the bank, up to about 3 m above the pool level, the ground vegetation was dense and tall

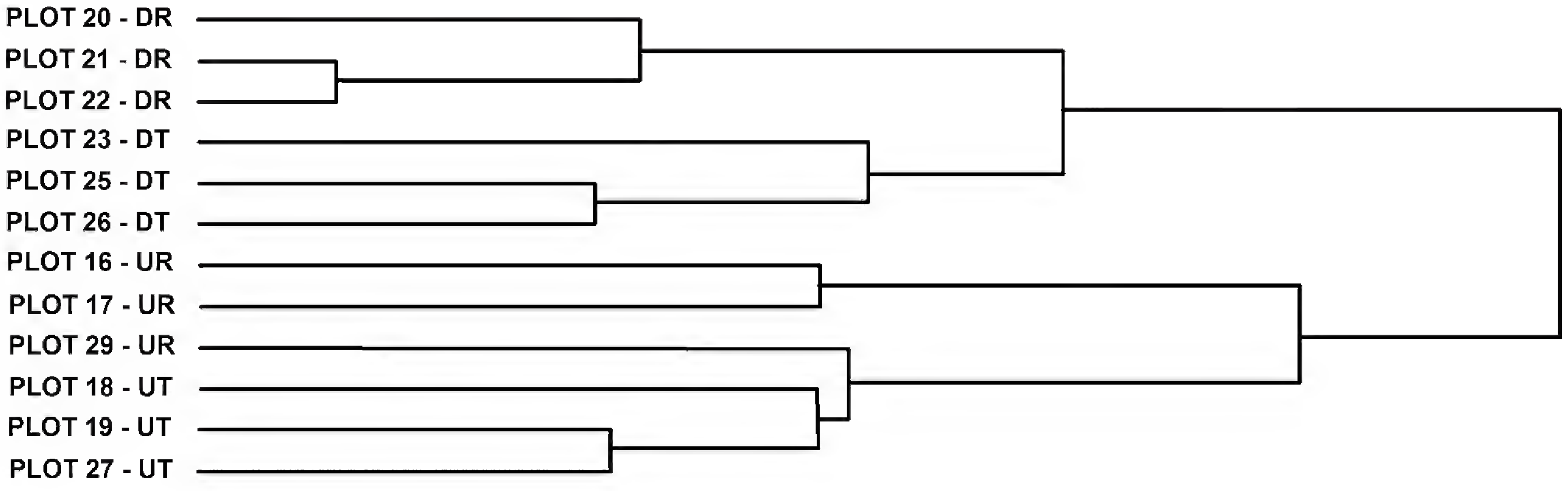


Fig. 12. Agglomerative hierarchical classification of plant species composition data from 12 sample plots at Lock 2 in Section 7. D = downstream of weir (fluctuating water levels), U = upstream of weir (stable water levels), R = riverside, T = top of bank.

(averaging 65 cm high and 85% foliage cover), and was characterized by several large, herbaceous daisies, including the exotic species *Aster subulatus*, *Cirsium vulgare* and *Urospermum picroides*, and the native species *Picris squarrosa* and *Sonchus hydrophilus*. It is noteworthy that *Sonchus hydrophilus*, although endemic to Australia, appears to be a polyploid derivative of the exotic species *Sonchus asper* (Boulos 1973).

Lignum (*Muehlenbeckia florulenta*) formed a shrub layer on top of the bank both upstream and downstream of the weir, but was denser upstream (average cover 20% versus 10%) and extended there to the water's edge, occurring in all three riverside plots, whereas it was absent from the riverside plots downstream of the weir. The cosmopolitan species, Common Couch (*Cynodon dactylon*), which appears to be introduced along the Murray and is treated here as an exotic species even though native forms occur elsewhere in Australia, was present both upstream and downstream of the weir but was markedly more abundant in the riverside plots upstream.

Downstream of the weir, the ground vegetation was lower and more open, with a greater diversity of species. From the water's edge to the top of the bank, up to about 4 m above the water level (in September 1987), it averaged 45 cm in height and 50% foliage cover. Species recorded solely or mainly downstream of the weir included the exotic species *Brassica tournefortii*, *Hordeum murinum*, *Hypochaeris glabra* and *Reichardia tingitana*, and the native species *Acacia stenophylla*, *Austrostipa* species (*scabra* group), *Chamaesyce drummondii*, *Eclipta platyglossa*, *Enchylaena tomentosa*, *Pseudognaphalium luteoalbum* and *Vittadinia cuneata*. Also, *Cyperus gymnocaulos*, although present in all 12 plots, was much more abundant downstream of the weir.

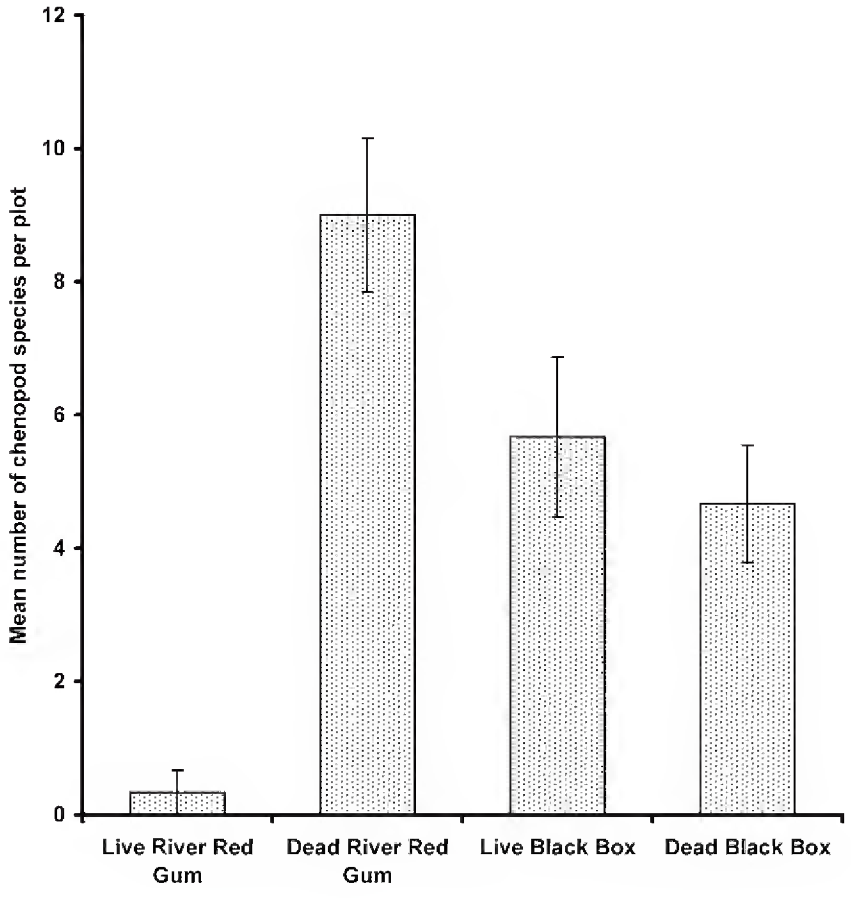


Fig. 13. Mean number of chenopod species per plot in live and dead (salt-killed) River Red Gum and Black Box stands at Dishers Creek Evaporation Basin in Section 6. Error bars are standard errors.

These results indicate that stabilisation of water levels in the lower Murray by the weir pools has impacted on the floodplain vegetation, resulting in reduced native species diversity and favouring some species and communities over others. It is likely that Communities 8 and 9, both of which are characterized by a band of Common Reed (*Phragmites australis*) along the water's edge, have become more extensive in the lower Murray, while Community 7, to which the riverside vegetation downstream of Lock 2 corresponds, has become less extensive.

Other studies in the South Australian reaches of the Murray have reported similar results. Walker *et al.* (1994) found that the distributions of aquatic and semi-aquatic plants along the margins of the Lock 2 and Lock 3 weir pools in 1988 were correlated with the amplitude of water level variations in 1982–87. Some species favoured areas below each weir where there was most variation in river levels, whereas other species favoured areas above each weir where water levels were most stable. From a broader survey of four weir pools in 1994, Blanch *et al.* (2000) suggested that an increase in the amplitude of river level fluctuations during low flows, from the current 10–20 cm range to 20–50 cm, would reinstate water regimes suitable to the majority of species surveyed.

Effects of salinisation

Floodplain ecosystems along the Murray are increasingly threatened by rising saline groundwater caused by both large-scale irrigation farming and land clearance (Macumber 1990, Williams 2001). The problem has been compounded by river regulation reducing the frequency of high-flow, salt-flushing events (Nielsen *et al.* 2003) and raising water levels in the many weir pools along the river, causing nearby groundwater levels to rise (Walker *et al.* 1996).

The effects of salinisation on floodplain vegetation were investigated during the 1987–88 survey at Dishers Creek Evaporation Basin near Calperum in Section 6, which has been used for disposal of irrigation effluents, resulting in salinisation and extensive death of both River Red Gum and Black Box trees. Three plots were sampled in dead River Red Gum stands along Dishers Creek on the western edge of the basin, and compared with three plots in live River Red Gum stands along the Murray adjacent to the south-western edge of the basin. Three more plots were sampled in dead Black Box stands west of Dishers Creek Evaporation Basin (within 1 km), and compared with three plots in live Black Box stands in the same area (apparently on slightly higher ground).

No significant effects were found on the number of native species recorded per plot. However, the mean number of exotic species per plot in dead stands (12.0 ± s.e. 1.0) was significantly higher than the mean in live stands (7.1 ± s.e. 0.9) (two-factor ANOVA, P = 0.007, no significant difference between River Red Gum and Black Box). The mean number of chenopod species per plot (all native) was also significantly higher in dead River Red Gum stands than in live ones, but not significantly different between live and dead Black Box stands (Fig. 13) (two-factor ANOVA, $P = 0.001$ for the interaction between the factors).

Differences in the species composition of the vegetation between live and dead stands of trees were investigated by pattern analysis. In an agglomerative hierarchical classification of the 12 plots based on their plant species composition and cover/abundance values, using the Bray and Curtis association measure and the Flexible UPGMA classification technique (PATN program), the main division was between the live River Red Gum plots and the other plots (Fig. 14). The next division was between the dead River Red Gum plots and the Black Box plots. The dead Black Box plots formed a subgroup within the Black Box group, but differences in species composition were less pronounced between live and dead Black Box plots than between live and dead River Red Gum plots (Fig. 14).

Apart from River Red Gum itself, the species most closely associated with live rather than dead River Red Gum plots (recorded in every plot in live stands but none in dead stands) were the native species *Brachyscome basaltica*, *Centipeda cunninghamii*, *Eclipta platyglossa*, *Paspalum distichum* and *Phragmites australis*, and the exotic species *Aster subulatus* and *Xanthium orientale*. These are all either daisies or grasses. The species most closely associated with dead River Red Gum plots were the native chenopod species *Atriplex lindleyi*, *A. rhagodioides*, *Einadia nutans* and *Tecticornia indica*, and the exotic species *Heliotropium curassavicum*, *Hordeum murinum*, *Schismus barbatus* and *Spergularia diandra*. The change in species composition in the River Red Gum plots amounted to a change from a River Red Gum community to Community 30, *Muehlenbeckia florulenta – Tecticornia pergranulata* shrubland.

Differences in species composition between live and dead Black Box stands were less marked. The species most closely associated with live Black Box stands were Black Box itself and *Enchylaena tomentosa*. The species most closely associated with dead Black Box stands were *Dissocarpus biflorus*, *Minuria cunninghamii*, *Wahlenbergia gracilenta* and *Wahlenbergia tumidifructa*. All of the above are native species. There was no change in plant community. All six Black Box plots, live or dead, were classified as Community 28, *Eucalyptus largiflorens – Atriplex rhagodioides* woodland.

Community 30, *Muehlenbeckia florulenta – Tecticornia pergranulata* shrubland, was encountered at other sites beneath dead, apparently salt-killed River Red Gums, and also in saline depressions in the Black Box zone with no dead trees. As salinity levels increase beyond the tolerance of the Lignum (*Muehlenbeckia florulenta*), Community 30 is apparently replaced by Community 32, *Tecticornia pergranulata – T. indica* shrubland. The two samphires *Tecticornia pergranulata* and *Tecticornia indica*, are widespread native species that grow in highly saline habitats, both coastal and inland (Wilson 1980). It is likely that Community 32 occurred naturally in the most saline sites on the Murray floodplain. However, most current examples appear to have replaced other communities as a result of increasing salinisation in recent times. All five plots sampled during the 1987–88 survey had dead trees or stumps, either River Red Gum or Black Box, and two plots also had dead Lignum shrubs. Whereas Community 30 is relatively rich in species, Community 32 is one of the most species-poor communities on the Murray floodplain (Appendix 1).

Floodplain vegetation is a particularly salt-sensitive ecosystem because it occupies a low point in the landscape, where saline water tends to accumulate via both groundwater intrusion and surface flows (Hart *et al.* 1990, Nielsen *et al.* 2003). The observations made during this survey indicate a sequence of change with increasing salinisation involving death of the trees; change to a Lignum-samphire shrubland (Community 30); gradual loss of the more salt-sensitive species; change to a lower, more open, much more depauperate samphire shrubland (Community 32); and, finally, complete loss of vegetation.

Threatened Species and Communities

Threatened species and communities are listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, the NSW *Threatened Species Conservation Act 1995*, the Victorian *Flora and Fauna Guarantee Act 1988* and the South Australian *National*

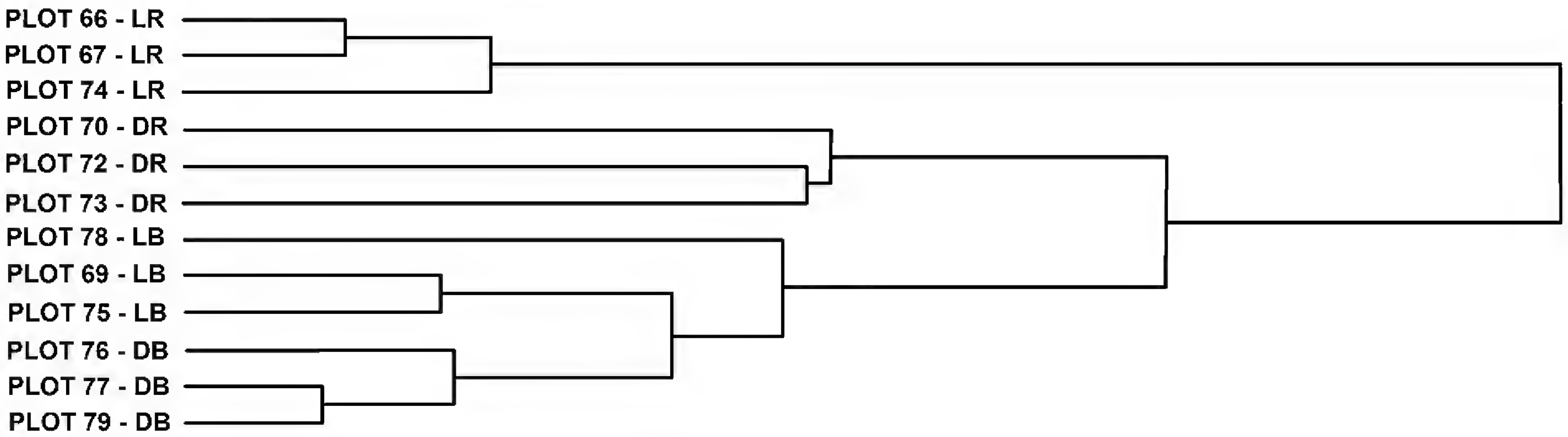


Fig. 14. Agglomerative hierarchical classification of plant species composition data from 12 sample plots at Dishers Creek Evaporation Basin in Section 6. L = stand of live trees, D = stand of dead trees (killed by salinisation), R = River Red Gum, B = Black Box.

Table 2. Plant species recorded in the survey that are listed under Commonwealth or state threatened species legislation E = endangered, R = rare, T = threatened, V = vulnerable

Scientific name	**Common name**	**Threatened species listing**				**Survey records**		
		Cmwlth	**NSW**	**Vic**	**SA**	**NSW**	**Vic**	**SA**
Allocasuarina luehmannii	Buloke			T		X		
Amphibromus fluitans	Floating Swamp Wallaby-grass	V	V				X	
Atriplex limbata	Spreading Saltbush			T			X	
Atriplex rhagodioides	Silver Saltbush			T			X	X
Brachyscome basaltica var. *gracilis*	Swamp Daisy				R	X	X	X
Callistemon brachyandrus	Prickly Bottlebrush				R			X
Callitriche sonderi	Matted Water Starwort				R	X		
Calocephalus sonderi	Pale Beauty-heads				R	X	X	X
Calotis scapigera	Tufted Burr-daisy				R	X	X	X
Crassula peduncularis	Purple Crassula				R		X	
Crassula sieberiana	Sieber’s Crassula				E	X	X	X
Cullen pallidum	Woolly Scurf-pea			T			X	
Eragrostis lacunaria	Purple Love-grass				R		X	X
Exocarpos strictus	Pale-fruit Cherry				R	X	X	
Fimbristylis aestivalis	Summer Fringe-rush				R	X		
Glycine tabacina	Variable Glycine				V	X		
Goodenia heteromera	Spreading Goodenia				R		X	
Hakea tephrosperma	Hooked Needlewood				R	X		
Helichrysum rutidolepis	Pale Everlasting				E		X	
Isotoma fluviatilis ssp. *australis*	Swamp Isotome				R	X	X	
Juncus amabilis					V	X	X	
Lobelia pratioides	Poison Lobelia				R	X		
Lomandra multiflora ssp. *multiflora*	Many-flower Mat-rush				E	X		
Maireana pentagona	Slender Fissure-plant				R		X	X
Mentha diemenica	Slender Mint				R		X	
Muehlenbeckia horrida ssp. *horrida*	Spiny Lignum				R			X
Myriophyllum crispatum	Upright Milfoil				V	X	X	
Nymphoides crenata	Wavy Marshwort			T	R	X	X	
Picris squarrosa	Squat Picris				R	X	X	X
Pratia concolor	Poison Pratia				R	X	X	X
Ranunculus inundatus	River Buttercup				R	X	X	
Ranunculus pumilio var. *politus*	Smooth-fruit Ferny Buttercup				V		X	
Rorippa laciniata	Jagged Bitter-cress				R	X	X	
Sclerolaena muricata var. *villosa*	Five-spine Bindyi				R	X	X	X
Swainsona greyana	Hairy Darling-pea			T				X
Swainsona phacoides	Dwarf Swainson-pea			T			X	
Viola betonicifolia ssp. *betonicifolia*	Showy Violet				E	X	X	

Parks and Wildlife Act 1972, although the last Act only lists species, not communities.

Only one threatened species listed under Commonwealth and NSW legislation was recorded during the survey: *Amphibromus fluitans* (Floating Swamp Wallaby-grass). *Amphibromus fluitans* was recorded in two survey plots, both within Section 2 in Victoria, in Community 3, *Eucalyptus camaldulensis – Poa labillardierei – Lachnagrostis filiformis* open-forest. Seven species listed under Victorian legislation were recorded, but only five of these were recorded in Victoria (Table 2). Thirty species listed under South Australian legislation were recorded, but only 11 of these were recorded in South Australia (Table 2).

Five of the Murray vegetation communities recognized in this survey correspond to threatened communities listed under Commonwealth or State legislation (Table 3). These include all four of the communities associated with rises within the floodplain. The fifth community, Community 25, *Eucalyptus largiflorens – Melaleuca lanceolata – Allocasuarina luehmannii* woodland, occurs in the Black Box zone in Section 4, but is a marginal floodplain remnant of an *Allocasuarina luehmannii* (Buloke) community that originally occurred on the adjacent rise, where it has now been cleared except for a few remnant Buloke trees.

Thus, all five of the Murray communities considered threatened under the legislation are essentially communities of the rises rather than the floodplain itself. None of the listed communities is restricted to the Murray floodplain – all occur beyond the Murray. However, there was a recent nomination to list the River Murray and associated wetlands, floodplains and groundwater ecosystems, from the junction of the Darling River to the sea, as a threatened ecological community under

Table 3. Murray vegetation communities that are listed under Commonwealth or state threatened species legislation

Threatened communities are not listed under South Australian legislation. C = critically endangered ecological community, E = endangered ecological community, T = threatened community

Murray community	**Threatened community listings**		
	Commonwealth	**New South Wales**	**Victoria**
25. *Eucalyptus largiflorens-Melaleuca lanceolata-Allocasuarina luehmannii* woodland	Buloke Woodlands of the Riverina and Murray-Darling Depression Bioregions (E)	*Allocasuarina luehmannii* Woodland in the Riverina and Murray-Darling Depression Bioregions (E)	Semi-arid Northwest Plains Buloke Grassy Woodlands Community (T)
34. *Eucalyptus microcarpa* open-forest	Grey Box (*Eucalyptus microcarpa*) Grassy Woodlands and Derived Native Grasslands of South-eastern Australia (E)	Inland Grey Box Woodland in the Riverina, NSW South Western Slopes, Cobar Peneplain, Nandewar and Brigalow Belt South Bioregions (E)	
35. *Eucalyptus melliodora* woodland	White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland (C)	White Box Yellow Box Blakely's Red Gum Woodland (E)	
36. *Callitris glaucophylla* woodland 37. *Dodonaea viscosa-Callitris gracilis* shrubland		Sandhill Pine Woodland in the Riverina, Murray-Darling Depression and NSW South Western Slopes Bioregions (E)	Semi-arid Herbaceous Pine Woodland Community (T)

Commonwealth legislation. The nomination was assessed by the Threatened Species Scientific Committee (2014), who concluded that it was eligible for listing as critically endangered. This part of the river system was accordingly listed as a critically endangered ecological community in August 2013. However, following objections from the farming sector and a change of government, its listing was disallowed by Federal Parliament in December 2013.

Conclusions

The present study is the first to describe floristic patterns in the floodplain vegetation of the River Murray at a broad scale, covering most of the length of the river, including the Edward-Wakool anabranch system. 37 plant communities were distinguished between Hume Dam and Lake Alexandrina, not including the vegetation of permanent wetlands and cleared areas. This represents much greater variation than might be expected from the uniformity of the tree layer, which is dominated by just two species, River Red Gum (*Eucalyptus camaldulensis*) and Black Box (*Eucalyptus largiflorens*). 21 communities were distinguished in the River Red Gum zone, which borders the river throughout the survey area. 12 communities were distinguished in the Black Box zone, which is associated with the less frequently flooded parts of the floodplain in the semi-arid reaches of the river, from the upper Murray-Edward junction downstream to Mannum. The other four communities were associated with rises within the floodplain that are rarely if ever flooded and support non-floodplain vegetation similar to that found on similar soils outside the floodplain.

Variation at the community level occurs both along the river and across the floodplain. The main floristic division among the River Red Gum communities was between Riverine Plain/Headwaters Zone communities of the upper Murray, and Mallee Zone communities of the lower Murray. Among the Black Box communities, the main floristic division was between inner floodplain communities and outer floodplain communities, with a further division between South Australian communities and New South Wales/Victorian communities. Major factors influencing the floristic patterns included flooding frequency/duration and soil salinity.

The changing floristic composion of the understorey vegetation along the river was reflected in the distribution of individual plant species. A total of 499 species, subspecies and varieties of plants (316 native and 183 exotic) were recorded in the 335 survey plots. Of these, apart from River Red Gum itself, only 12 species were recorded in every river section. Most species had a much more restricted distribution, reflecting the changes in climate, geomorphology and soils along the river.

The study provides critical evidence of the condition of the Murray floodplain vegetation in the 1980s, before the compounding effects of the severe and prolonged Millenium Drought in south-eastern Australia from 1997 to 2010. Tree health was poor even before the drought. It was best at the upper end of the river, where 84% of trees were assessed as healthy, and became steadily worse downstream, being poorest in the lower reaches below the Darling Junction, where only 60% of trees were assessed as healthy (and the criterion for 'healthy' was a broad one – less than 40% of the crown dead). Obvious causes of tree death in the lower reaches were soil salinisation and inundation of eucalypt stands by raised water levels upstream of weirs. However, while some low-lying sites have become wetter, tree health has been affected more widely because the lower Murray floodplain in general has become drier as a result of the high level of water extraction, mainly for irrigation, throughout the Murray-Darling Basin. This has meant fewer, less extensive, less sustained floods, an effect that is most pronounced in the lower reaches of the river (Walker and Thoms 1993, Maheshwari *et al.* 1995, Dyer 2002, Roberts 2004, CSIRO 2008). Reduced flooding has also meant less effective leaching of salt from floodplain soils in the lower Murray. Consistent with these effects, the condition of Black Box trees was found to be significantly worse in 1987–88 than the condition of River Red Gum trees (71% of River Red Gum trees assessed as healthy, compared with only 56% of Black Box trees).

The situation was exacerbated during the Millenium Drought, when overbank flows were largely absent along the lower Murray between 1994 and 2010 (Holland *et al.* 2013). Surveys in 2002–04 found poor River Red Gum and Black Box health (Murray-Darling Basin Commission 2003, Smith and Kenny 2005, Brett Lane and Associates 2005), and indicated a decline in tree health since our 1987–88 survey. Tree health deteriorated further as the drought continued. Cunningham *et al.* (2009) assessed that 72% of River Red Gum stands, and 92% of Black Box stands along the river were in a stressed condition in 2009, and that the extent of stressed stands had been 66% lower in 2003. The situation was worse in the Mallee Zone than in the Riverine Plain. Following the breaking of the drought with a major flood over the summer of 2010–11, a significant improvement in the condition of both River Red Gum and Black Box trees was reported at several sites along the Murray in 2012 (Bennetts and Jolly 2012, Henderson *et al.* 2012a, 2012b).

More recent surveys of vegetation condition imply that the decline in tree health along the Murray has mainly occurred during the drought. The Murray-Darling Basin Commission (2003) reported a severe decline in tree health in the 12 months prior to their February 2003 survey. Brett Lane and Associates (2005) reported a severe decline in tree health between 2002 and 2004. Cunningham *et al.* (2009) reported a severe decline between 2003 and 2009. The results from our 1987–88 survey are important because they show that poor tree health was already evident before the drought, and was a serious concern even without the compounding effects of the drought. The patterns that we found in 1987–88 – poorer tree health in the lower reaches of the river below the Darling Junction, and poorer tree health for Black Box than for River Red Gum – were the same patterns as subsequently reported during the drought.

A further indicator of vegetation health available from the 1987–88 survey was the density of eucalypt regeneration. Like the health of the trees themselves, regeneration was poorest in the lower Murray below the Darling Junction, and Black Box regeneration was much sparser overall than River Red Gum regeneration. The poor eucalypt regeneration in the lower Murray is due to a combination of factors, including reduced flooding, increasing salinisation, overgrazing and less post-logging regeneration. Coupled with the poor condition of the Black Box trees, the poor regeneration of Black Box suggests that its long-term future along the Murray, particularly below the Darling Junction, is tenuous, even though it is a dominant component of the vegetation.

The findings of poor tree health and sparse regeneration below the Darling Junction coincide with the most heavily regulated part of the River Murray, where the reduction in flooding due to upstream storages and water extraction has been greatest (Walker and Thoms 1993, Maheshwari *et al.* 1995, Dyer 2002). Reduced flooding, which means not only less water for the trees but also less flushing of accumulated salt from the saline Mallee Zone floodplain, is implicated as the primary cause of the observed decline of River Red Gum and Black Box on the lower Murray.

Another indicator of vegetation health is the extent of weed invasion. The integrity of the floodplain vegetation of the Murray has been severely compromised by weed invasion, but this problem has received relatively little attention in recent reviews (Roberts 2004, Jensen and Walker 2012). Exotic species comprised 37% of all species recorded in our survey plots. Weeds were common throughout the survey area, but were most prevalent in the climatically wetter sections of the river, both at the downstream end (below Mannum) and at the upstream end (above Tocumwal). The mean number of exotic species per plot equalled or exceeded the number of native species in these sections of the river, whereas native species outnumbered exotic species in the other river sections. Communities of the River Red Gum zone and the rises were generally weedier than those of the Black Box zone. Exotic species strongly influenced the community classification. They were the dominant overstorey species in two communities (willows *Salix* species) and outnumbered native species in the understorey of another eight communities. At the lower end of the river, below Mannum, the River Red Gums that originally fringed the river have been mostly replaced by dense thickets of the exotic Weeping Willow (*Salix babylonica*).

Other factors that have impacted on the floodplain vegetation at the community level have been river regulation and soil salinisation. Stabilization of water levels in the lower Murray by construction of a series of weirs and barrages has favoured the spread of some communities at the expense of others. The favoured communities, Communities 8 and 9, which are characterized by stands of Common Reeds (*Phragmites australis*) along the water's edge, appear to be artefacts of river regulation. Salinisation has also brought about community changes, resulting in death of eucalypts and replacement of eucalypt communities by shrub communities dominated by samphires *Tecticornia* species (Communities 30 and 32). The samphire community characteristic of the most saline sites (Community 32) is one of the most species-poor communities on the Murray floodplain.

Logging along the Murray in New South Wales and Victoria has resulted in extensive replacement of old growth River Red Gum forests and woodlands by more even-aged stands of straight young trees (Mac Nally *et al.* 2011). Forest structure prior to European settlement is thought to have consisted of large old widely-spreading trees interspersed with a mosaic of mixed-age stands of varying sizes (Jacobs 1955). Following the recent conversion of many areas of

State Forest along the Murray in both New South Wales and Victoria to National Park or Regional Park, and thus the cessation of logging in these areas, they should now revert gradually to mature forest and woodland.

The River Murray and associated wetlands, floodplains and groundwater ecosystems from the junction of the Darling River to the sea were recently nominated for listing as a threatened ecological community under Commonwealth legislation. Following a detailed assessment, the Threatened Species Scientific Committee (2014) concluded that this part of the river system was eligible for listing as critically endangered. It was accordingly listed as a critically endangered ecological community in August 2013. However, following objections from the farming sector and a change of government, its listing was disallowed by Federal Parliament in December 2013, which was an unprecedented rejection of the advice of the Threatened Species Scientific Committee.

The results of the 1987–88 survey support the Threatened Species Scientific Committee's (2014) assessment that the floodplain vegetation along the lower Murray below the Darling Junction is severely degraded and warrants listing as a critically endangered ecological community. Furthermore, the results show that the deteriorating condition of the vegetation was already evident in the 1980s and, although exacerbated by the subsequent Millenium Drought, it is not just a consequence of that drought. The results are consistent with the conclusion that the primary cause of the decline has been river regulation and water extraction for irrigation. The air photo mapping study carried out in parallel with our field survey confirmed that extensive vegetation degradation was evident along the Murray before the drought and was worse in the Mallee Zone than on the Riverine Plain (Margules and Partners *et al.* 1990). The rate of deterioration has increased rapidly since the 1980s and although there has been some improvement since the breaking of the drought, the poor condition of the River Murray floodplain vegetation, an Australian icon, remains a major conservation and management issue. The impacts of climate change – higher temperatures and reduced rainfall – have compounded the problem (Cai and Cowan 2008a, 2008b, Cai *et al.* 2009, Mac Nally *et al.* 2011) and will continue to do so at an increasing rate.

Acknowledgements

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Appendix 1. Plant community descriptions

Exotic species are indicated by asterisks. Height and foliage cover are mean values. Mean number of species per plot includes unidentified species, whereas mean numbers of native and exotic species per plot refer only to identified species.

River Red Gum Zone

1. *Eucalyptus camaldulensis – Eleocharis acuta – Pseudoraphis spinescens* open-forest
2. *Eucalyptus camaldulensis – Eleocharis acuta – Wahlenbergia fluminalis* open-forest
3. *Eucalyptus camaldulensis – Poa labillardierei – Lachnagrostis filiformis* open-forest
4. *Eucalyptus camaldulensis – Poa labillardierei – Hemarthria uncinata* open-forest
5. *Eucalyptus camaldulensis – Carex tereticaulis* open-forest
6. *Eucalyptus camaldulensis – Paspalidium jubiflorum – Senecio quadridentatus* open-forest
7. *Eucalyptus camaldulensis – Paspalidium jubiflorum – *Cynodon dactylon* woodland
8. *Eucalyptus camaldulensis – Cyperus gymnocaulos* woodland
9. *Eucalyptus camaldulensis – Phragmites australis* woodland
10. *Eucalyptus camaldulensis – Austrodanthonia caespitosa* woodland
11. *Eucalyptus camaldulensis – Eucalyptus largiflorens* open-forest
12. *Eucalyptus camaldulensis – Muehlenbeckia florulenta* woodland
13. *Eucalyptus camaldulensis – *Bromus diandrus – *Vulpia bromoides* open-forest
14. *Eucalyptus camaldulensis – *Bromus diandrus – Austrodanthonia caespitosa* open-forest
15. *Eucalyptus camaldulensis – *Cynodon dactylon* woodland
16. **Salix x rubens* scrub
17. **Salix babylonica* scrub
18. *Callistemon brachyandrus – Muehlenbeckia florulenta* shrubland
19. *Lachnagrostis filiformis – *Cynodon dactylon* grassland
20. *Pseudoraphis spinescens – Eleocharis acuta* herbland
21. *Centipeda cunninghamii – Polygonum plebeium* herbland

Black Box Zone

22. *Eucalyptus largiflorens – Eleocharis acuta* open-forest
23. *Eucalyptus largiflorens – Muehlenbeckis florulenta – Chenopodium nitrariaceum* woodland
24. *Eucalyptus largiflorens – Muehlenbeckia florulenta – Atriplex semibaccata* woodland
25. *Eucalyptus largiflorens – Melaleuca lanceolata – Allocasuarina luehmannii* woodland
26. *Eucalyptus largiflorens – Melaleuca lanceolata – Atriplex rhagodiodes* woodland
27. *Eucalyptus largiflorens – Atriplex nummularia* open-woodland
28. *Eucalyptus largiflorens – Atriplex rhagodioides* woodland
29. *Chenopodium nitrariaceum – Muehlenbeckia florulenta* shrubland
30. *Muehlenbeckia florulenta – Tecticornia pergranulata* shrubland
31. *Atriplex vesicaria – Tecticornia triandra* shrubland
32. *Tecticornia pergranulata – Tecticornia indica* shrubland
33. *Sporobolus mitchellii – Atriplex leptocarpa* grassland

Rises within the Floodplain

34. *Eucalyptus microcarpa* open-forest
35. *Eucalyptus melliodora* woodland
36. *Callitris glaucophylla* woodland
37. *Dodonaea viscosa – Callitris gracilis* shrubland

RIVER RED GUM ZONE

1. *Eucalyptus camaldulensis – Eleocharis acuta – Pseudoraphis spinescens* open-forest (Fig. 15)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	24	30	*Eucalyptus camaldulensis*
Tall herb	0.8	15/0	*Cyperus exaltatus* or absent
Low herb	0.3	55	*Eleocharis acuta*, *Centipeda cunninghamii*, *Pseudoraphis spinescens*, *Alternanthera denticulata*, *Paspalidium jubiflorum*, *Rumex brownii*, *Lachnagrostis filiformis*, *Myriophyllum crispatum*

Number of plots: 26

Mean number of species per plot (including unidentified): 14.4 (range 7–31)

Mean number of native species per plot: 12 (range 6–22)

Mean number of exotic species per plot: 2.3 (range 0–9)

Mean percentage of chenopod species per plot: 0

River Red Gum condition: 81% healthy, 15% unhealthy, 4% dead (n = 361)

River Red Gum regeneration: 838 per ha (6% <1 m, 17% 1–4 m, 77% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 1.65 (sheep 0.54, cattle 0.67, rabbit 0.21, pig 0.02, kangaroo 0.21)

Distribution: NSW (13 plots), Victoria (12 plots) and South Australia (1 plot), in Sections 1 (1 plot), 3 (9 plots), 4 (11 plots), 5 (3 plots) and 6 (2 plots). Found in sites subject to frequent flooding. Covers extensive low-lying areas away from the river in Sections 3 and 4; elsewhere found close to the river or to other water bodies.

Notes: This community includes the tallest Murray floodplain forests. In River Section 3 the average height of the trees at maturity exceeds 30 m, with some stands exceeding 45 m (NSW Forestry Commission 1985, Chesterfield 1986). The relatively low average height for the sample plots reflects their history of intensive logging, which has seen old growth trees replaced by younger, lower trees.

2. *Eucalyptus camaldulensis – Eleocharis acuta – Wahlenbergia fluminalis* open-forest

Layer	Height (m)	Foliage cover (%)	Main species
Tree	21	40	*Eucalyptus camaldulensis*
Herb	0.3	70	*Eleocharis acuta*, *Lachnagrostis filiformis*, *Ranunculus inundatus*, *Juncus amabilis*, *Wahlenbergia fluminalis*, *Centipeda cunninghamii*, *Rumex brownii*, *Myriophyllum crispatum*

Number of plots: 4

Mean number of species per plot (including unidentified): 33 (range 26–47)

Mean number of native species per plot: 22.5 (range 20–28)

Mean number of exotic species per plot: 10 (range 6–18)

Mean percentage of chenopod species per plot: 0

River Red Gum condition: 76% healthy, 19% unhealthy, 5% dead (n = 42)

River Red Gum regeneration: 169 per ha (11% <1 m, 22% 1–4 m, 67% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 4.88 (sheep 1.5, cattle 1.38, rabbit 1, kangaroo 1)

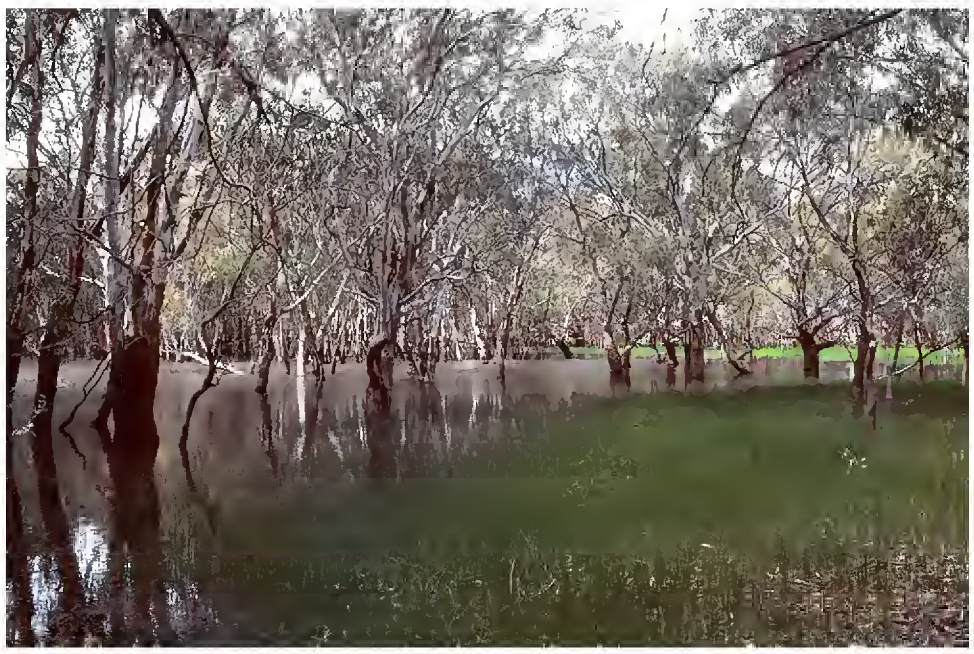

Fig. 15. Community 1, *Eucalyptus camaldulensis-Eleocharis acuta-Pseudoraphis spinescens* open-forest, near Nyah in Section 4, showing new growth of *Eleocharis acuta* as floodwaters recede.

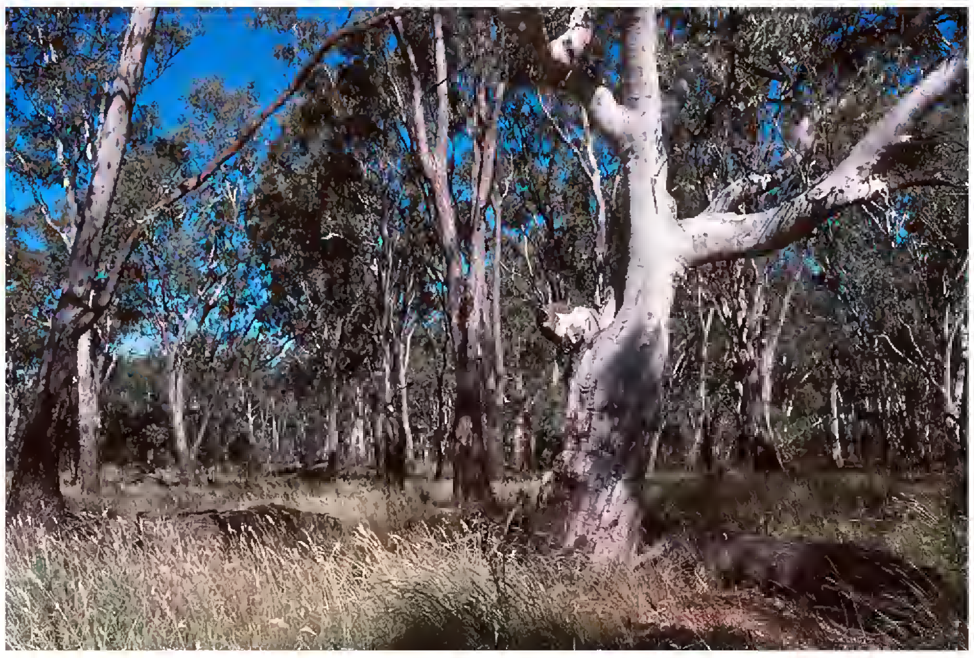

Fig. 16. Community 3, *Eucalyptus camaldulensis-Poa labillardierei-Lachnagrostis filiformis* open-forest, near Corowa in Section 1, with an understorey dominated by *Austrodanthonia duttoniana*.

Distribution: NSW (2 plots) and Victoria (2 plots), in Sections 3 (1 plot) and 4 (3 plots). Similar to the more widespread Community 1. The two communities were found together at 3 of the 4 sites. In each case, Community 2 occurred on higher ground than Community 1.

3. *Eucalyptus camaldulensis – Poa labillardierei – Lachnagrostis filiformis* open-forest (Fig. 16)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	23	45	*Eucalyptus camaldulensis*
Shrub	5	15/0	*Acacia dealbata*, but mostly absent
Tall herb	1	30	*Poa labillardierei*, *Carex tereticaulis*, *Juncus amabilis*
Low herb	0.3	45	*Lachnagrostis filiformis*, **Cynodon dactylon*, **Lolium perenne x rigidum*, **Cirsium vulgare*, *Centipeda cunninghamii*, **Hypochaeris radicata*, *Eleocharis acuta*, *Wahlenbergia fluminalis*

Number of plots: 30

Mean number of species per plot (including unidentified): 37.1 (range 21–57)

Mean number of native species per plot: 20.0 (range 7–30)

Mean number of exotic species per plot: 16.7 (range 4–30)

Mean percentage of chenopod species per plot: 0

River Red Gum condition: 76% healthy, 19% unhealthy, 5% dead (n = 330)

River Red Gum regeneration: 762 per ha (30% <1 m, 40% 1–4 m, 30% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 2.45 (sheep 0.17, cattle 1.07, rabbit 0.48, kangaroo 0.73)

Distribution: NSW (12 plots) and Victoria (18 plots), in Sections 1 (11 plots), 2 (5 plots), 3 (10 plots) and 4 (4 plots). Generally found close to the river or to other water bodies, or in floodplain depressions. Community 3 and the weedy Community 13 are the main floodplain communities in Sections 1 and 2, with Community 3 typically found in more frequently flooded sites than Community 13.

4. *Eucalyptus camaldulensis – Poa labillardierei – Hemarthria uncinata* open-forest

Layer	Height (m)	Foliage cover (%)	Main species
Tree	24	30	*Eucalyptus camaldulensis*
Shrub	7	5/0	*Acacia dealbata* or absent
Tall herb	0.9	20	*Poa labillardierei*, *Carex tereticaulis*, *Juncus amabilis*
Low herb	0.2	60	*Hemarthria uncinata*, *Persicaria prostrata*, **Lolium perenne x rigidum*, **Hypochaeris radicata*, **Cirsium vulgare*, **Vulpia bromoides*, **Cynodon dactylon*, **Paspalum dilatatum*

Number of plots: 7

Mean number of species per plot (including unidentified): 33.3 (range 22–43)

Mean number of native species per plot: 14.6 (range 7–22)

Mean number of exotic species per plot: 18.6 (range 13–26)

Mean percentage of chenopod species per plot: 0

River Red Gum condition: 84% healthy, 15% unhealthy, 1% dead (n = 89)

River Red Gum regeneration: 50 per ha (14% <1 m, 7% 1–4 m, 79% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 10.86 (sheep 0.43, cattle 0.86, rabbit 9.29, kangaroo 0.29)

Distribution: NSW (4 plots) and Victoria (3 plots), in Sections 1 (2 plots) and 2 (5 plots). Similar to the more widespread Community 3 and, like that community, typically found close to the river or to other water bodies. Community 4 was often associated with sandy soils, particularly in Boomanoomana State Forest in Section 2, where 3 of the 7 plots were located.

5. *Eucalyptus camaldulensis – Carex tereticaulis* open-forest (Fig. 17)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	23	40	*Eucalyptus camaldulensis*
Tall herb	1	45	*Carex tereticaulis*, *Poa labillardierei*
Low herb	0.2	35	*Wahlenbergia fluminalis*, **Hypochaeris glabra*, **Lactuca serriola*, **Sonchus oleraceus*, **Lolium perenne x rigidum*, **Bromus hordeaceus*, **Vulpia bromoides*, **Bromus diandrus*

Number of plots: 11

Mean number of species per plot (including unidentified): 35.3 (range 21–50)

Mean number of native species per plot: 19.5 (range 13–29)

Mean number of exotic species per plot: 15.6 (range 8–26)

Mean percentage of chenopod species per plot: 1%

River Red Gum condition: 81% healthy, 14% unhealthy, 5% dead (n = 136)

River Red Gum regeneration: 966 per ha (43% <1 m, 27% 1–4 m, 30% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 2.14 (sheep 0.05, cattle 0.59, rabbit 0.23, pig 0.05, kangaroo 1.23)

Distribution: NSW (7 plots) and Victoria (4 plots), in Sections 3 (7 plots) and 4 (4 plots, all in the eastern half). Community 5 is one of the two main floodplain communities in Section 3, together with Community 6.

Notes: Chesterfield (1986) has suggested that logging and grazing may have led to an expansion of Community 5 at the expense of Community 6 (*E. camaldulensis – Paspalidium jubiflorum – Senecio quadridentatus* open-forest). His reasoning is that *Carex tereticaulis* tends to be associated with higher tree densities than *Paspalidium jubiflorum*, and that *Carex tereticaulis* is unpalatable to stock, whereas *Paspalidium jubiflorum* is palatable.

6. *Eucalyptus camaldulensis – Paspalidium jubiflorum – Senecio quadridentatus* open-forest (Fig. 18)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	20	35	*Eucalyptus camaldulensis*
Herb	0.4	55	*Paspalidium jubiflorum, Wahlenbergia fluminalis, *Hypochaeris glabra, Lachnagrostis filiformis, *Lolium perenne x rigidum, Senecio quadridentatus, *Sonchus oleraceus,* Centipeda cunninghamii

Number of plots: 25

Mean number of species per plot (including unidentified): 31.3 (range 20–50)

Mean number of native species per plot: 17.3 (range 10–28)

Mean number of exotic species per plot: 13.6 (range 5–23)

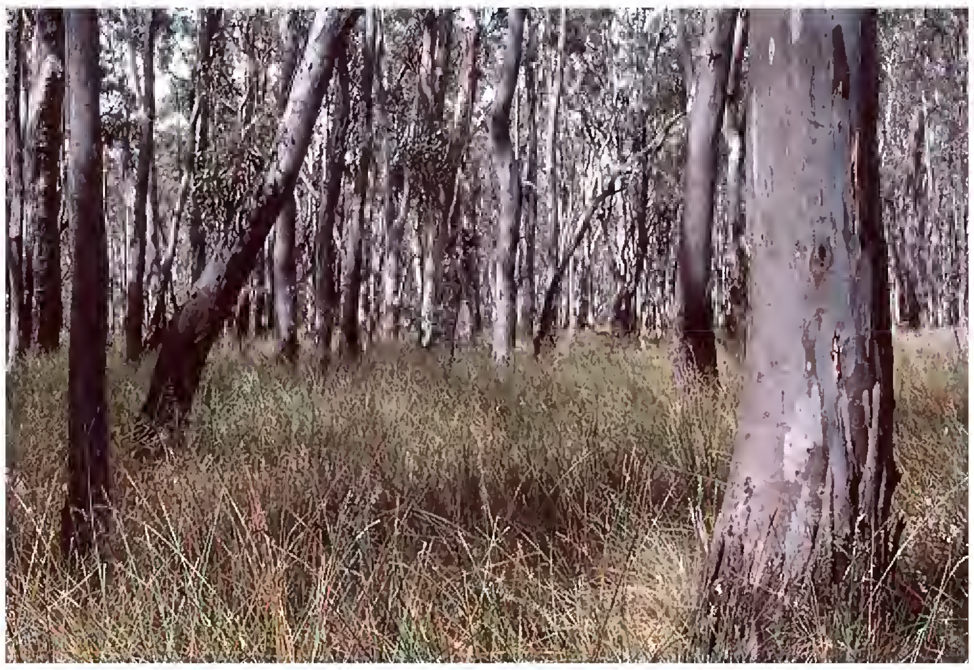

Fig. 17. Community 5, *Eucalyptus camaldulensis-Carex tereticaulis* open-forest, in Millewa State Forest in Section 3, with an understorey dominated by *Carex tereticaulis.*

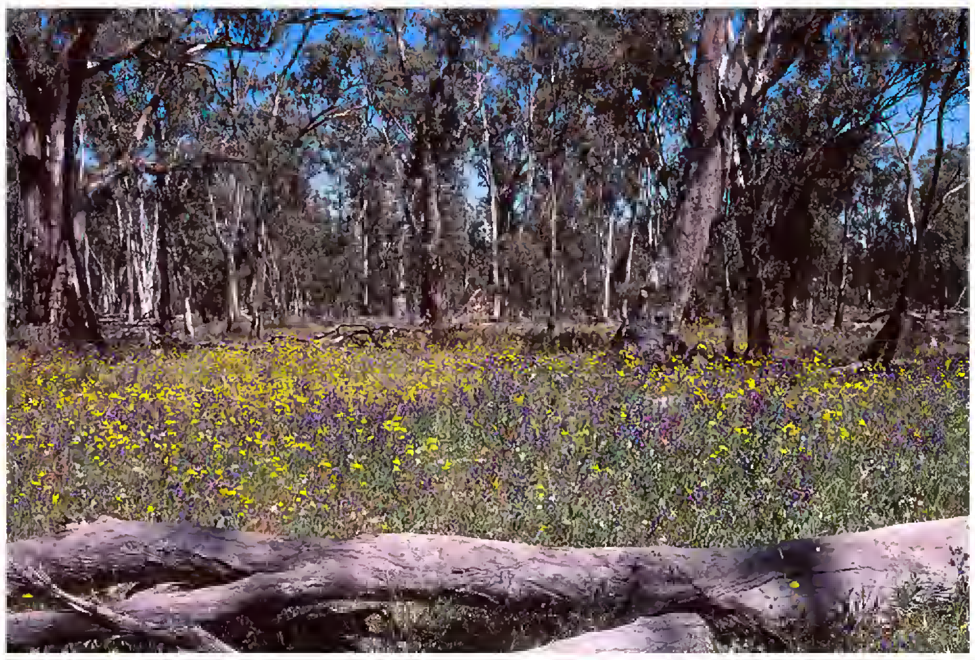

Fig. 18. Community 6, *Eucalyptus camaldulensis-Paspalidium jubiflorum-Senecio quadridentatus* open-forest, in Werai State Forest (Edward River) in Section 4, with an understorey dominated by *Xerochrysum bracteatum and *Echium plantagineum.*

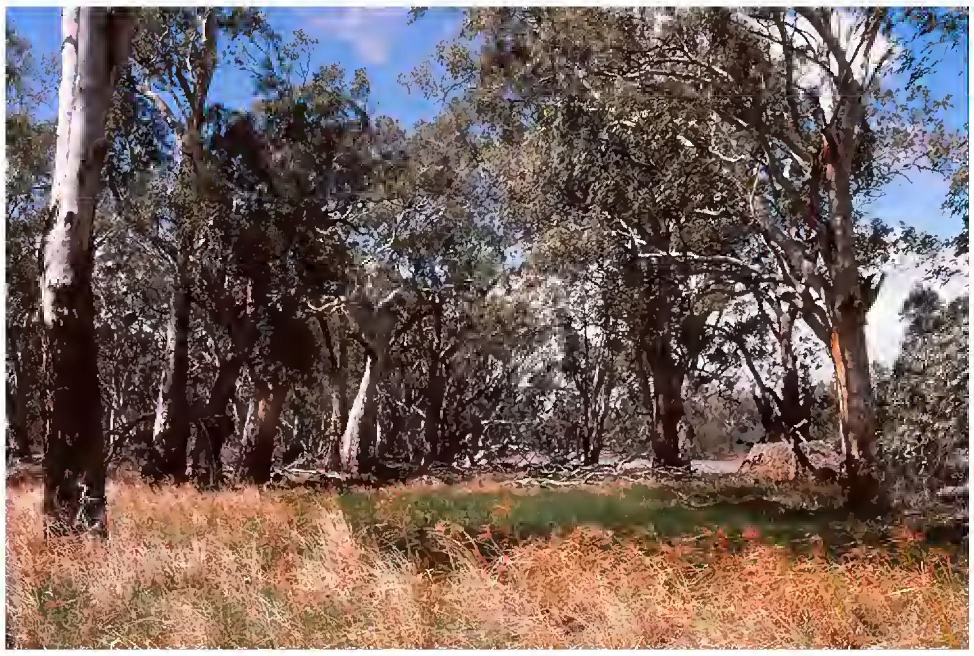

Fig. 19. Community 7, *Eucalyptus camaldulensis-Paspalidium jubiflorum-*Cynodon dactylon* woodland, in Chowilla Station in Section 6, with *Cyperus exaltatus* in the understorey, surrounding a patch of *Eleocharis acuta.*

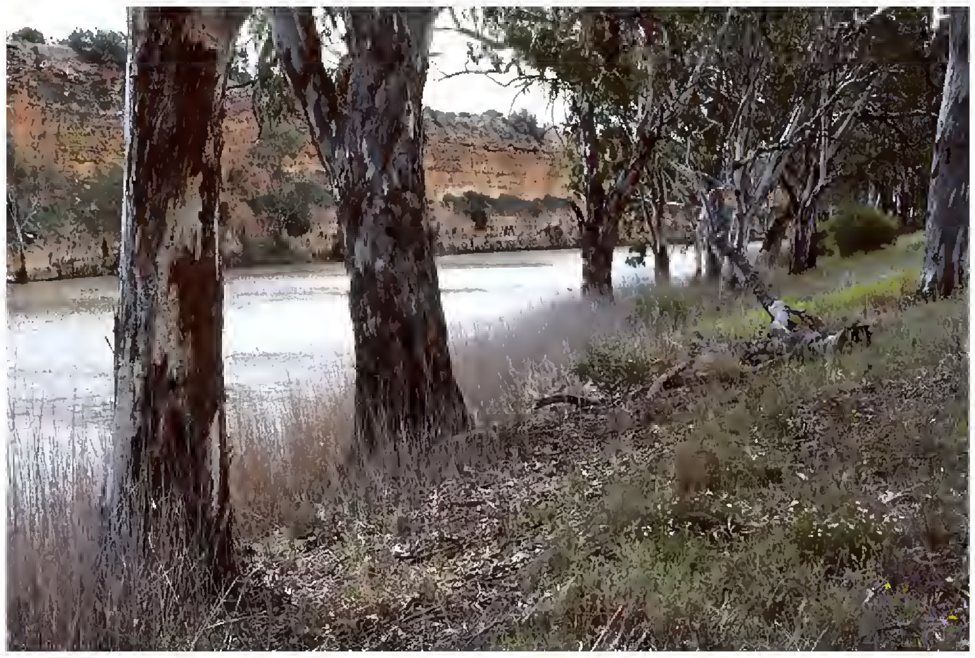

Fig. 20. Community 8, *Eucalyptus camaldulensis-Cyperus gymnocaulos* woodland, near Waikerie in Section 7, showing a band of *Phragmites australis* along the water's edge, which is typical of the South Australian section of the river.

Mean percentage of chenopod species per plot: 1%

River Red Gum condition: 72% healthy, 19% unhealthy, 9% dead (n = 298)

River Red Gum regeneration: 861 per ha (13% <1 m, 41% 1–4 m, 46% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 5 (sheep 0.58, cattle 0.58, rabbit 1.68, pig 0.12, kangaroo 2.02, emu 0.02)

Distribution: NSW (22 plots) and Victoria (3 plots), in Sections 2 (2 plots), 3 (5 plots) and 4 (18 plots). The most extensive River Red Gum community in Section 4 and one of the two most extensive communities in Section 3 (together with Community 5).

7. *Eucalyptus camaldulensis – Paspalidium jubiflorum – *Cynodon dactylon* woodland (Fig. 19)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	21	25	*Eucalyptus camaldulensis*
Tall shrub	6	5/0	*Acacia stenophylla*, but mostly absent
Low shrub	1.6	5/0	*Muehlenbeckia florulenta*, but mostly absent
Tall herb	1	15/0	*Phragmites australis* or *Cyperus exaltatus* beside the water, but mostly absent
Low herb	0.4	60	*Paspalidium jubiflorum*, **Cynodon dactylon*, *Wahlenbergia fluminalis*, **Hypochaeris glabra*, **Sonchus oleraceus*, *Centipeda cunninghamii*, *Eclipta platyglossa*, *Cyperus gymnocaulos*

Number of plots: 28

Mean number of species per plot (including unidentified): 29.6 (range 16–48)

Mean number of native species per plot: 18.5 (range 9–30)

Mean number of exotic species per plot: 10.8 (range 5–23)

Mean percentage of chenopod species per plot: 5%

River Red Gum condition: 76% healthy, 19% unhealthy, 5% dead (n = 290)

River Red Gum regeneration: 463 per ha (33% <1 m, 38% 1–4 m, 29% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 6.21 (sheep 3.43, cattle 0.27, rabbit 1.16, kangaroo 1.36)

Distribution: NSW (13 plots), Victoria (5 plots) and South Australia (10 plots), in Sections 4 (5 plots), 5 (7 plots), 6 (11 plots) and 7 (5 plots). The most extensive River Red Gum community in Section 5 and the eastern half of Section 6.

8. *Eucalyptus camaldulensis – Cyperus gymnocaulos* woodland (Fig. 20)

Layer	Height (m)	Foliage Cover (%)	Main species
Tree	20	25	*Eucalyptus camaldulensis*
Shrub	1.8	5	*Muehlenbeckia florulenta*
Tall herb	1.7	15	*Phragmites australis* beside the water
Low herb	0.4	55	*Cyperus gymnocaulos*, *Sporobolus mitchellii*, *Eclipta platyglossa*, *Wahlenbergia fluminalis*, **Cynodon dactylon*, **Sonchus oleraceus*, *Paspalidium jubiflorum*, *Sonchus hydrophilus*

Number of plots: 12

Mean number of species per plot (including unidentified): 24.3 (range 19–32)

Mean number of native species per plot: 15.5 (range 9–23)

Mean number of exotic species per plot: 8.5 (range 6–13)

Mean percentage of chenopod species per plot: 3%

River Red Gum condition: 70% healthy, 15% unhealthy, 15% dead (n = 129)

River Red Gum regeneration: 273 per ha (0% <1 m, 30% 1–4 m, 70% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 4.17 (sheep 2.21, cattle 0.21, rabbit 0.17, kangaroo 1.58)

Distribution: All plots in South Australia, in Sections 6 (5 plots) and 7 (7 plots). Found close to the river or to other water bodies. The most extensive River Red Gum community in Section 7 and the western half of Section 6.

9. *Eucalyptus camaldulensis – Phragmites australis* woodland

Layer	Height (m)	Foliage cover (%)	Main species
Tree	16	20	*Eucalyptus camaldulensis*
Shrub	2.5	5	*Muehlenbeckia florulenta*
Tall herb	1.7	55	*Phragmites australis*, *Typha* species, *Schoenoplectus validus*
Low herb	0.4	35	**Cynodon dactylon*, *Asperula gemella*, *Cyperus gymnocaulos*, *Paspalidium jubiflorum*, *Sonchus hydrophilus*, **Cirsium vulgare*, **Bromus diandrus*, *Picris squarrosa*

Number of plots: 5

Mean number of species per plot (including unidentified): 18.8 (range 10–31)

Mean number of native species per plot: 11.2 (range 8–19)

Mean number of exotic species per plot: 7.4 (range 2–11)

Mean percentage of chenopod species per plot: 2%

River Red Gum condition: 80% healthy, 10% unhealthy, 10% dead (n = 50)

River Red Gum regeneration: 60 per ha (0% <1 m, 67% 1–4 m, 33% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 0.8 (cattle 0.4, rabbit 0.4)

Distribution: All plots in South Australia, in Sections 7 (4 plots) and 8 (1 plot). Found on the edge of the river where there is a wide band of *Phragmites australis* on low-lying ground at the water's edge. On steeper riverbanks, where there is only a narrow band of *Phragmites australis*, the vegetation type is Community 8.

10. *Eucalyptus camaldulensis – Austrodanthonia caespitosa* woodland (Fig. 21)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	18	25	*Eucalyptus camaldulensis*
Tall herb	0.7	5	*Juncus flavidus*, *Carex tereticaulis*, *Poa labillardierei*
Low herb	0.3	65	*Austrodanthonia caespitosa*, *Wahlenbergia fluminalis*, **Lolium perenne x rigidum*, **Vulpia myuros*, *Austrodanthonia duttoniana*, **Hypochaeris glabra*, *Lachnagrostis filiformis*, **Bromus hordeaceus*

Number of plots: 8

Mean number of species per plot (including unidentified): 35.4 (range 26–50)

Mean number of native species per plot: 18.4 (range 9–25)

Mean number of exotic species per plot: 16.9 (range 10–26)

Mean percentage of chenopod species per plot: 1%

River Red Gum condition: 72% healthy, 22% unhealthy, 6% dead (n = 123)

River Red Gum regeneration: 28 per ha (45% <1 m, 33% 1–4 m, 22% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 7.06 (sheep 0.06, cattle 3.69, horse 0.19, rabbit 0.94, kangaroo 2.13, emu 0.06)

Distribution: NSW (1 plot) and Victoria (7 plots), in Sections 2 (3 plots), 3 (3 plots) and 4 (2 plots). Typically found in less frequently flooded sites on the outer fringes of the River Red Gum zone.

11. *Eucalyptus camaldulensis – E. largiflorens* open-forest

Layer	Height (m)	Foliage cover (%)	Main species
Tree	18	35	*Eucalyptus camaldulensis*, *E. largiflorens*
Shrub	1.9	15/0	*Muehlenbeckia florulenta* or *Exocarpos strictus* or *Acacia* spp. or absent
Tall herb	0.8	15/0	*Cyperus exaltatus* beside the water, but mostly absent
Low herb	0.1	25	**Hypochaeris glabra*, **Sonchus oleraceus*, **Vulpia myuros*, **Lolium perenne x rigidum*, *Wahlenbergia fluminalis*, **Cynodon dactylon*, *Paspalidium jubiflorum*, *Oxalis perennans*

Number of plots: 13

Mean number of species per plot (including unidentified): 24.7 (range 12–41)

Mean number of native species per plot: 15.3 (range 9–24)

Mean number of exotic species per plot: 8.8 (range 3–16)

Mean percentage of chenopod species per plot: 5%

River Red Gum condition: 55% healthy, 37% unhealthy, 8% dead (n = 122)

Black Box condition: 49% healthy, 44% unhealthy, 7% dead (n = 95)

River Red Gum regeneration: 67 per ha (46% <1 m, 26% 1–4 m, 28% >4 m)

Black Box regeneration (8 plots): 469 per ha (10% <1 m, 35% 1–4 m, 55% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 4.77 (sheep 1.88, cattle 0.58, rabbit 1.19, pig 0.04, kangaroo 1, emu 0.08)

Distribution: NSW (7 plots) and Victoria (6 plots), in Sections 4 (8 plots) and 5 (5 plots). Typically found at the junction of the River Red Gum and Black Box zones, either on the floodplain or on river and creek banks (particularly where the banks are steep and high). However, *Eucalyptus largiflorens* was absent from 5 of the 13 plots (*E. camaldulensis* was present in every plot).

Notes: A rather heterogeneous grouping that includes one plot where the vegetation appeared to be changing from a River Red Gum community to a Black Box community, and another plot where the reverse appeared to be occurring. The latter was a waterside plot upstream of Torrumbarry Weir (Section 4), which would have been located away from the water's edge before construction of the weir. The reason for the apparent vegetation change at the other plot was unclear.

12. *Eucalyptus camaldulensis* – *Muehlenbeckia florulenta* woodland (Fig. 22)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	18	25	*Eucalyptus camaldulensis*, some *E. largiflorens*
Tall shrub	7	5	*Acacia stenophylla*, sometimes forming dense stands
Low shrub	1.6	10	*Muehlenbeckia florulenta*
Low herb	0.4	60	*Paspalidium jubiflorum*, **Bromus rubens*, **Hypochaeris glabra*, *Cyperus gymnocaulos*, *Wahlenbergia fluminalis*, *Einadia nutans*, **Sonchus oleraceus*, **Cynodon dactylon*

Number of plots: 13

Mean number of species per plot (including unidentified): 27.2 (range 14–42)

Mean number of native species per plot: 17.1 (range 8–28)

Mean number of exotic species per plot: 9.9 (range 6–14)

Mean percentage of chenopod species per plot: 10%

River Red Gum condition: 50% healthy, 35% unhealthy, 15% dead (n = 124)

Black Box condition: 95% healthy, 5% unhealthy, 0% dead (n = 40)

River Red Gum regeneration (11 plots): 43 per ha (5% <1 m, 53% 1–4 m, 42% >4 m)

Black Box regeneration (4 plots): 13 per ha (100% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 4.77 (sheep 1, cattle 0.35, rabbit 2.77, kangaroo 0.65)

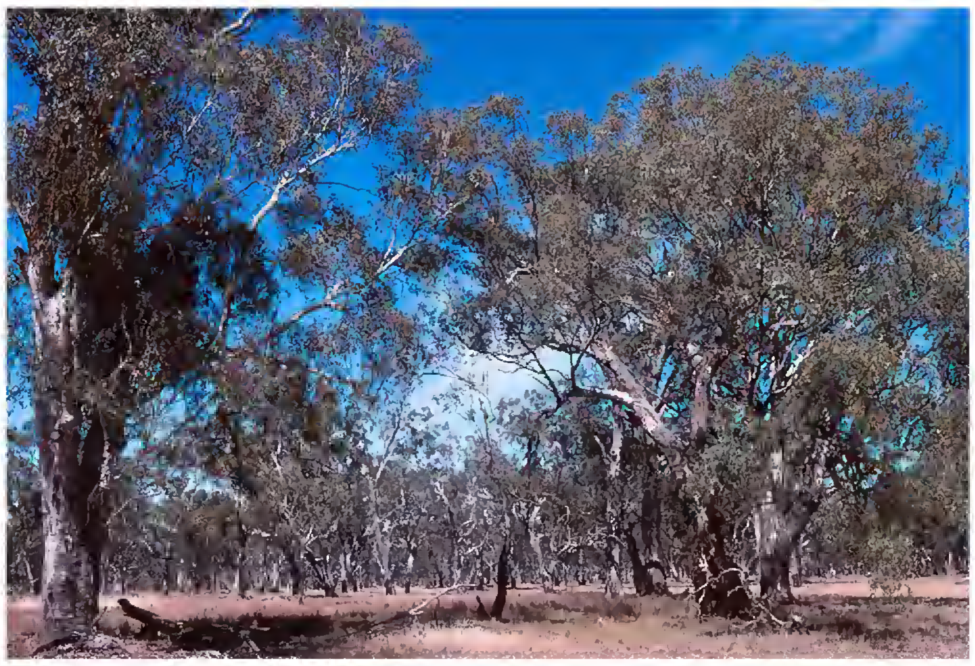

Fig. 21. Community 10, *Eucalyptus camaldulensis-Austrodanthonia caespitosa* woodland, on Ulupna Island in Section 2.

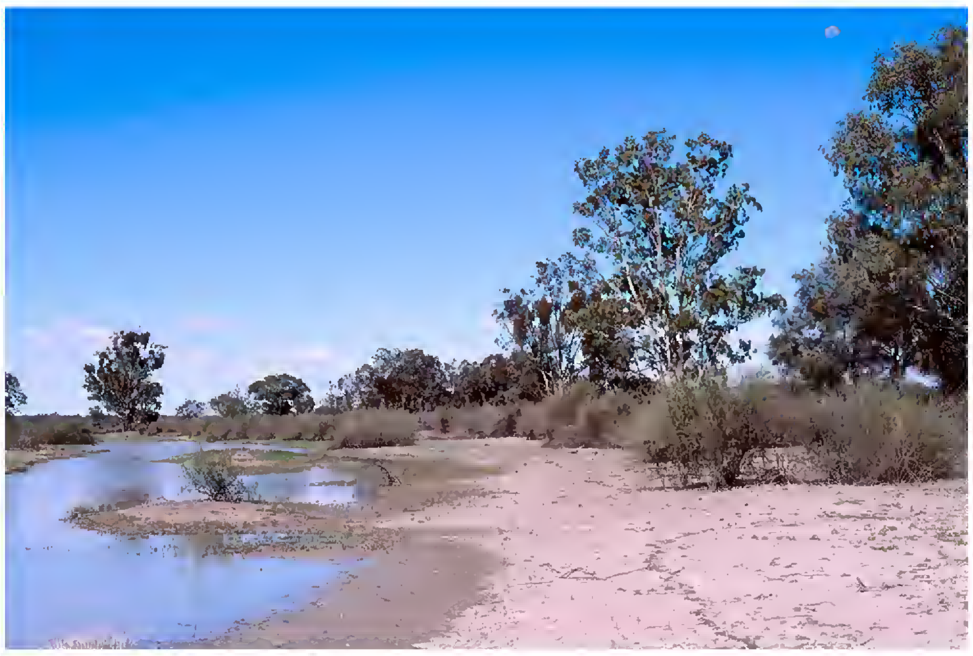

Fig. 22. Community 12, *Eucalyptus camaldulensis-Muehlenbeckia florulenta* woodland, near Murtho in Section 6, with a dense *Muehlenbeckia florulenta* understorey.

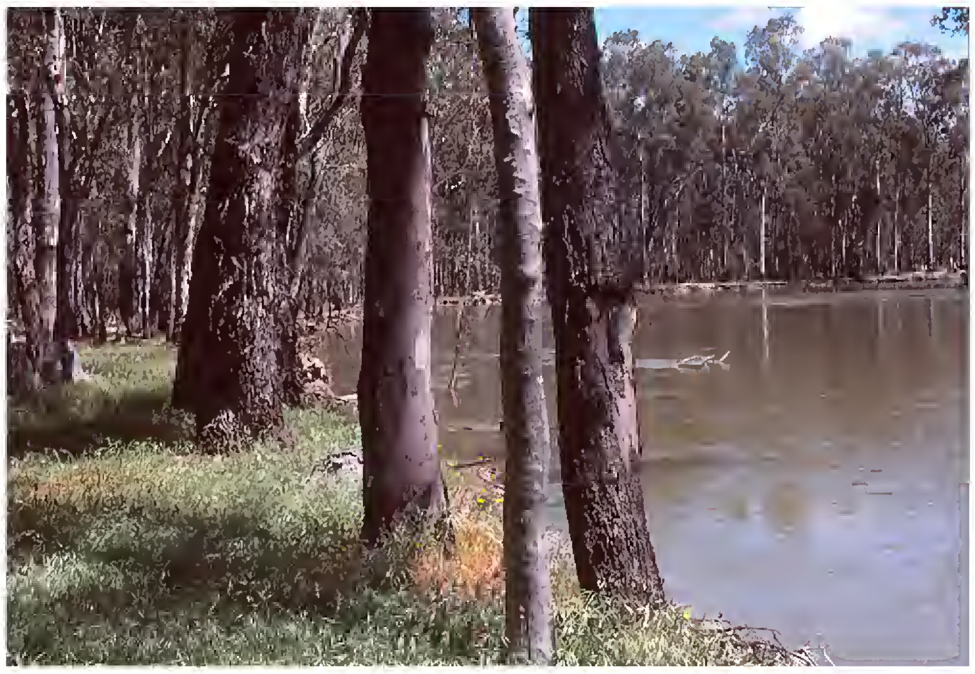

Fig. 23. Community 13, *Eucalyptus camaldulensis-*Bromus diandrus-*Vulpia bromoides* open-forest, in Barmah State Forest in Section 3, with an understorey dominated by **Bromus diandrus.*

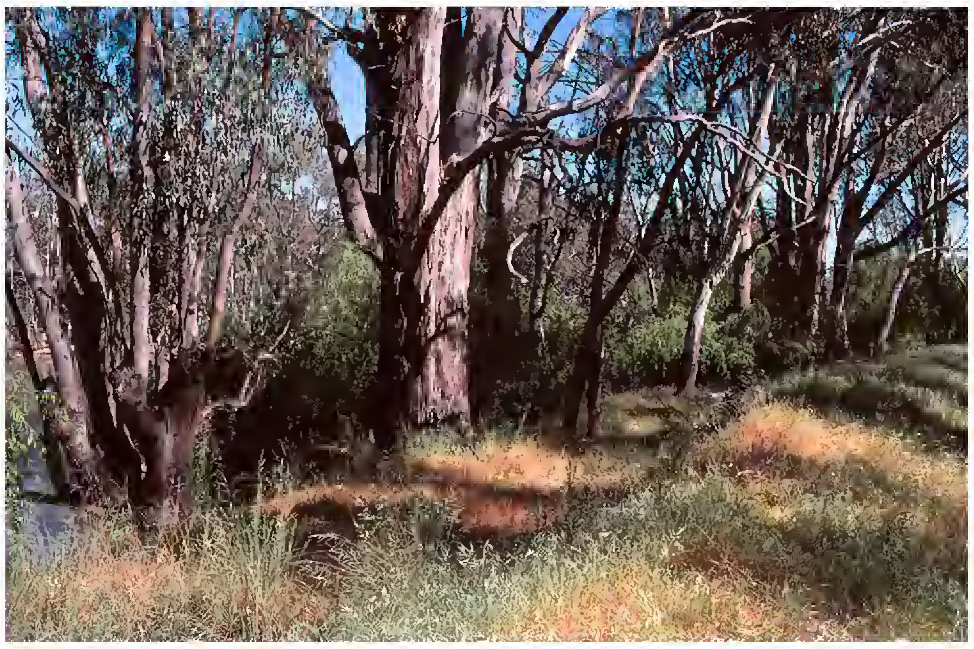

Fig. 24. Community 14, *Eucalyptus camaldulensis-*Bromus diandrus-Austrodanthonia caespitosa* open-forest, near Stevens Weir (Edward River) in Section 4, with **Salix babylonica* growing along the water's edge and **Bromus diandrus* and *Austrodanthonia duttoniana* dominant on top of the bank.

Distribution: Victoria (4 plots) and South Australia (9 plots), in Sections 5 (4 plots), 6 (3 plots) and 7 (6 plots). Typically found on sandy soils at the junction of the River Red Gum and Black Box zones, either on the floodplain or, more often, on high river and creek banks.

Notes: *Eucalyptus largiflorens* was present in 4 of the 13 plots and the only eucalypt in two of those plots (i.e. no *E. camaldulensis*).

13. *Eucalyptus camaldulensis – *Bromus diandrus – *Vulpia bromoides* open-forest (Fig. 23)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	22	35	*Eucalyptus camaldulensis*
Shrub	2.5–6	15/0	*Acacia dealbata* (6 m) or **Salix* spp. (6 m) or *Exocarpos strictus* (2.5 m), but mostly absent
Tall herb	0.8	15/0	*Carex tereticaulis*, *Juncus flavidus*, *J. amabilis* or absent
Low herb	0.3	70	**Bromus diandrus*, **Bromus hordeaceus*, **Lolium perenne x rigidum*, **Vulpia bromoides*, **Hypochaeris radicata*, **Hordeum murinum*, **Cynodon dactylon*, **Cirsium vulgare*

Number of plots: 21

Mean number of species per plot (including unidentified): 29.1 (range 13–49)

Mean number of native species per plot: 10.7 (range 3–24)

Mean number of exotic species per plot: 18.1 (range 8–26)

Mean percentage of chenopod species per plot: 0

River Red Gum condition: 79% healthy, 18% unhealthy, 3% dead (n = 267)

River Red Gum regeneration: 356 per ha (37% <1 m, 27% 1–4 m, 36% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 6.17 (sheep 0.07, cattle 2.69, horse 0.05, rabbit 2.52, pig 0.02, kangaroo 0.81)

Distribution: NSW (13 plots) and Victoria (8 plots), in Sections 1 (10 plots), 2 (5 plots), 3 (5 plots) and 4 (1 plot). Occurs in various situations where the native understorey vegetation has been largely replaced by weeds. Typically occurs in less frequently flooded sites than adjacent, less weedy River Red Gum communities. One of the two main floodplain communities in Sections 1 and 2, together with Community 3.

14. *Eucalyptus camaldulensis – *Bromus diandrus – Austrodanthonia caespitosa* open-forest (Fig. 24)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	21	30	*Eucalyptus camaldulensis*
Shrub	1.5–6	30/0	*Acacia dealbata* (6 m) or **Salix babylonica* (5 m) or *Chenopodium nitrariaceum* (1.5 m) or absent
Herb	0.3	55	**Bromus diandrus, Austrodanthonia caespitosa, *Bromus hordeaceus, *Lolium perenne x rigidum, *Avena barbata, *Hordeum murinum, *Vulpia myuros, *Cirsium vulgare, *Hordeum marinum*

Number of plots: 6

Mean number of species per plot (including unidentified): 28.8 (range 14–38)

Mean number of native species per plot: 12.2 (range 5–16)

Mean number of exotic species per plot: 16.5 (range 9–22)

Mean percentage of chenopod species per plot: 2%

River Red Gum condition: 57% healthy, 29% unhealthy, 14% dead (n = 90)

River Red Gum regeneration: 238 per ha (4% <1 m, 21% 1–4 m, 75% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 1.58 (sheep 0.08, cattle 0.67, rabbit 0.42, kangaroo 0.42)

Distribution: NSW (5 plots) and Victoria (1 plot), all in Section 4. A mixed group of very weedy plots. Four plots were on high riverbanks; the other two plots were associated with dry floodways.

Notes: The *Acacia dealbata* and **Salix babylonica* layers occurred in riverbank plots, while the *Chenopodium nitrariaceum* layer was in a floodway plot. The dead trees were mainly in the other floodway plot, which appeared to be salt-affected, the understorey being dominated by the salt-tolerant **Hordeum marinum*.

15. *Eucalyptus camaldulensis – *Cynodon dactylon* woodland (Fig. 25)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	18	20	*Eucalyptus camaldulensis*
Tall shrub	8	10/0	**Salix babylonica* beside the water, but mostly absent
Low shrub	1.8	15	*Muehlenbeckia florulenta*, *Enchylaena tomentosa*
Tall herb	1.5	5/0	*Schoenoplectus validus* beside the water, but mostly absent
Low herb	0.2	65	**Cynodon dactylon*, **Bromus rubens*, *Cyperus gymnocaulos*, **Medicago polymorpha*, **Hordeum murinum*, *Sonchus hydrophilus*, **Cirsium vulgare*, **Rumex crispus*

Number of plots: 12

Mean number of species per plot (including unidentified): 34.5 (range 21–51)

Mean number of native species per plot: 13.8 (range 7–26)

Mean number of exotic species per plot: 20 (range 14–27)

Mean percentage of chenopod species per plot: 7%

River Red Gum condition: 60% healthy, 13% unhealthy, 27% dead (n = 120)

River Red Gum regeneration: 88 per ha (0 <1 m, 10% 1–4 m, 90% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 7.5 (cattle 3.96, rabbit 3.54)

Distribution: All plots in South Australia, in Sections 7 (3 plots) and 8 (9 plots). Occurs in degraded sites where the native understorey vegetation has been largely replaced by weeds. The most extensive River Red Gum community in Section 8. The Lower Murray equivalent of the weedy _E. camaldulensis_ – *_Bromus diandrus_ communities of the Upper Murray (Communities 13 and 14).

Notes: The high number of dead trees is a result of raised water levels and, in one plot, salinisation.

16. *_Salix x rubens_ scrub

Layer	**Height (m)**	**Foliage cover (%)**	**Main species**
Tree	16	15/0	_Eucalyptus camaldulensis_ or absent
Shrub	7	65	*_Salix x rubens_
Tall herb	1	15	_Poa labillardierei_, _Phragmites australis_
Low herb	0.3	15	*_Hypochaeris radicata_, *_Vulpia bromoides_, *_Conyza bonariensis_, _Lachnagrostis filiformis_, *_Bromus catharticus_, *_Juncus flavidus_, *_Cirsium vulgare_, *_Trifolium campestre_

Number of plots: 2

Mean number of species per plot (including unidentified): 31.5 (range 17–46)

Mean number of native species per plot: 12.5 (range 5–20)

Mean number of exotic species per plot: 18 (range 12–24)

Mean percentage of chenopod species per plot: 0

River Red Gum condition: 64% healthy, 36% unhealthy, 0 dead (n = 11)

River Red Gum regeneration: 525 per ha (0 <1 m, 52% 1–4 m, 48% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 1.25 (cattle 1, kangaroo 0.25)

Distribution: Both plots in NSW, in Sections 1 (1 plot) and 3 (1 plot). Occurs in scattered sites where there are stands of *_Salix x rubens_ fringing the river. *_Salix x rubens_ grows further down the riverbank than _Eucalyptus camaldulensis_ and parts of both plots were in water at the time of the survey.

Notes: Although there was dense eucalypt regeneration in one plot, much of it appeared unhealthy, being shaded by the *_Salix_.

17. *_Salix babylonica_ scrub (Fig. 26)

Layer	**Height (m)**	**Foliage cover (%)**	**Main species**
Shrub	9	60	*_Salix babylonica_
Herb	0.6	25	_Juncus aridicola_, *_Aster subulatus_, _Hydrocotyle verticillata_, *_Helminthotheca echioides_, _Triglochin procera_, *_Cirsium vulgare_, _Lachnagrostis filiformis_, _Azolla filiculoides_, _Phragmites australis_

Number of plots: 6

Mean number of species per plot (including unidentified): 25.2 (range 17–33)

Mean number of native species per plot: 12.5 (range 8–23)

Mean number of exotic species per plot: 12 (range 9–20)

Mean percentage of chenopod species per plot: 0

Mean grazing index (number of dropping clusters per 20 m): 0.25 (cattle 0.17, kangaroo 0.08)

Distribution: All plots in South Australia, in Sections 6 (1 plot) and 8 (5 plots). However, stands of *_Salix babylonica_ occur sporadically in other river sections as well. The community is most extensive in Section 8, where *_Salix babylonica_ typically occurs in a 20–40 m wide strip between a constructed levee and the river. It is the main riverside vegetation along this part of the river and is virtually continuous below Murray Bridge. *_Salix babylonica_ grows further down the riverbank than _Eucalyptus camaldulensis_ and large parts of all plots (40–80%) were in water at the time of the survey.

18. _Callistemon brachyandrus_ – _Muehlenbeckia florulenta_ shrubland (Fig. 27)

Layer	**Height (m)**	**Foliage cover (%)**	**Main species**
Tall shrub	4	20	_Callistemon brachyandrus_, _Muehlenbeckia florulenta_
Low shrub	0.6	5	_Enchylaena tomentosa_, _Maireana brevifolia_
Herb	0.2	55	*_Bromus rubens_, _Cyperus gymnocaulos_, *_Hypochaeris glabra_, *_Avena barbata_, *_Brassica tournefortii_, _Calotis cuneifolia_, *_Euphorbia terracina_, _Einadia nutans_

Number of plots: 2

Mean number of species per plot (including unidentified): 30.5 (range 30–31)

Mean number of native species per plot: 17 (range 15–19)

Mean number of exotic species per plot: 13.5 (range 12–15)

Mean percentage of chenopod species per plot: 20%

Mean grazing index (number of dropping clusters per 20 m): 1 (rabbit 1)

Distribution: Only encountered at Morgan Conservation Park in Section 7 in South Australia, growing in very sandy soil on the riverbank and on the floodplain behind.

19. *Lachnagrostis filiformis – *Cynodon dactylon* grassland

Layer	Height (m)	Foliage cover (%)	Main species
Sapling	3	5	*Eucalyptus camaldulensis*
Herb	0.1	60	*Lachnagrostis filiformis, *Cynodon dactylon, Crassula sieberiana, *Lolium perenne x rigidum, Persicaria prostrata, *Hypochaeris radicata, Centipeda cunninghamii, Eragrostis elongata*

Number of plots: 3

Mean number of species per plot (including unidentified): 25.3 (range 19–32)

Mean number of native species per plot: 11.7 (range 8–14)

Mean number of exotic species per plot: 13.7 (range 11–18)

Mean percentage of chenopod species per plot: 0

River Red Gum regeneration: 558 per ha (7% <1 m, 66% 1–4 m, 27% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 3.83 (cattle 1.17, rabbit 0.33, kangaroo 2.33)

Distribution: All plots in Victoria, in Section 2. Occurs on recent sand deposits, usually point bars.

Notes: This community represents the early stages of colonisation of the broad point bar deposits (beaches) of Section 2.

20. *Pseudoraphis spinescens – Eleocharis acuta* herbland (Fig. 28)

Layer	Height (m)	Foliage cover (%)	Main species
Herb	0.2	85	*Pseudoraphis spinescens*, *Eleocharis acuta*, *Centipeda cunninghamii*, *Lachnagrostis filiformis*, *Persicaria hydropiper*, *P. prostrata*, *Alternanthera denticulata*, **Ludwigia peploides*

Number of plots: 4

Mean number of species per plot (including unidentified): 9.5 (range 3–18)

Mean number of native species per plot: 8 (range 3–15)

Mean number of exotic species per plot: 1.5 (range 0–3)

Mean percentage of chenopod species per plot: 0

Mean grazing index (number of dropping clusters per 20 m): 1.5 (cattle 1.38, horse 0.13)

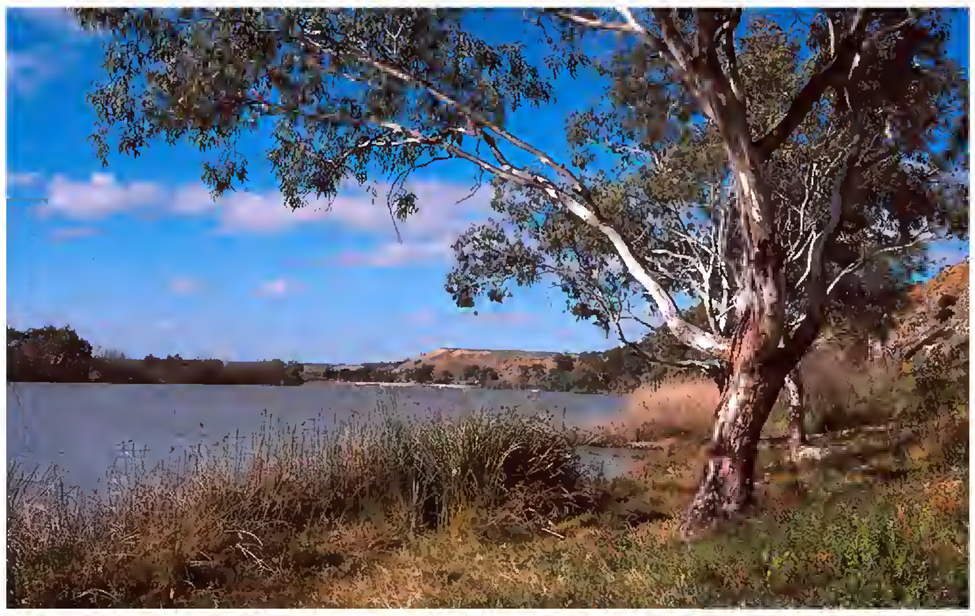

Fig. 25. Community 15, *Eucalyptus camaldulensis-*Cynodon dactylon* woodland, near Mypolonga in Section 8, with *Schoenus validus* growing along the water's edge and **Cynodon dactylon* and **Medicago polymorpha* dominant away from the water.

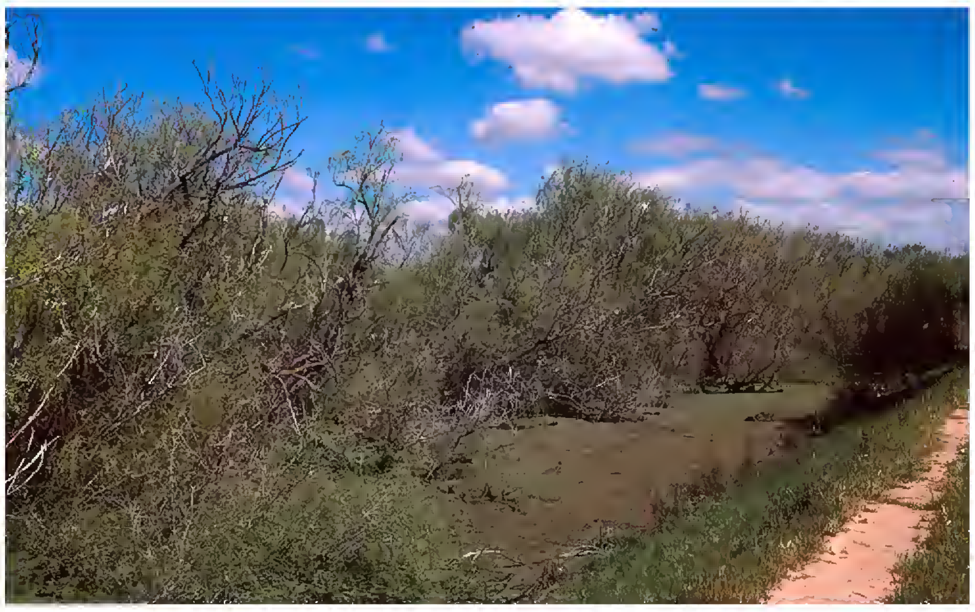

Fig. 26. Community 17, **Salix babylonica* scrub, near Ponde in Section 8.

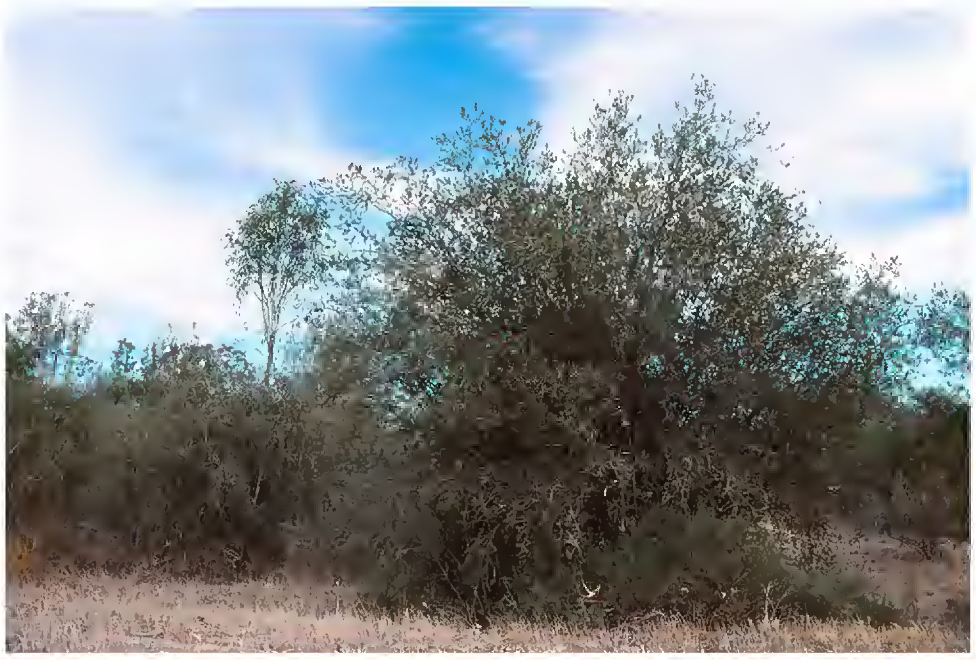

Fig. 27. Community 18, *Callistemon brachyandrus-Muehlenbeckia florulenta* shrubland, in Morgan Conservation Park in Section 7.

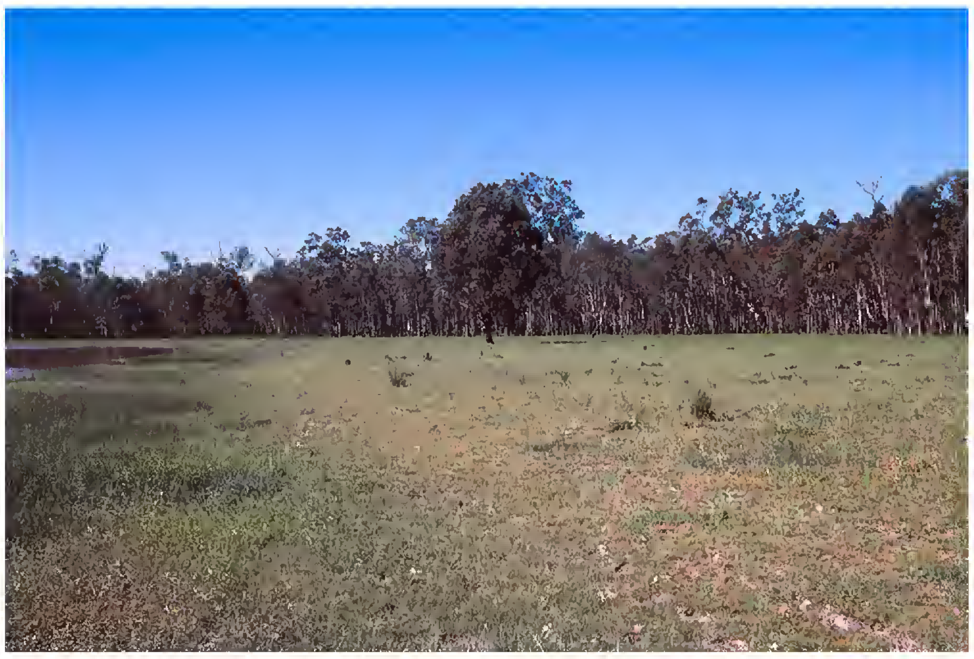

Fig. 28. Community 20, *Pseudoraphis spinescens-Eleocharis acuta* herbland, in Barmah State Forest in Section 3, with *Pseudoraphis spinescens* dominant.

Distribution: NSW (1 plot) and Victoria (3 plots), in Sections 3 (plots) and 4 (observed). Occurs on flat, low-lying areas where flooding is too frequent and prolonged for *Eucalyptus camaldulensis* to grow.

Notes: Varies from *Pseudoraphis spinescens* grassland to *Eleocharis acuta* sedgeland.

21. *Centipeda cunninghamii – Polygonum plebeium* herbland (Fig. 29)

Layer	Height (m)	Foliage cover (%)	Main species
Sapling	10	5	*Eucalyptus camaldulensis*
Herb	0.2	65	*Centipeda cunninghamii*, *Polygonum plebeium*, *Persicaria prostrata*, *Pseudognaphalium luteoalbum*, *Centipeda minima*, *Lachnagrostis filiformis*, *Alternanthera denticulata*, *Rumex crystallinus*

Number of plots: 5

Mean number of species per plot (including unidentified): 25 (range 14–35)

Mean number of native species per plot: 16 (range 11–21)

Mean number of exotic species per plot: 9 (range 7–16)

Mean percentage of chenopod species per plot: 0

River Red Gum regeneration: 4065 per ha (93% <1 m, 7% 1–4 m, 0.2% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 9.7 (sheep 3.5, cattle 0.5, rabbit 5.2, kangaroo 0.5)

Distribution: NSW (4 plots) and Victoria (1 plot), in Sections 2 (1 plot), 4 (2 plots) and 5 (2 plots). Occurs in depressions and on gently sloping edges of billabongs, i.e. in sites that are subject to frequent flooding.

Notes: In addition to the eucalypt seedlings included in the counts, there were thousands of seedlings under 5 cm high. Germination is prolific after flooding, but most of the seedlings are killed by later flooding. Saplings become established only on the outer edges of the community and on rises within it.

BLACK BOX ZONE

22. *Eucalyptus largiflorens – Eleocharis acuta* open-forest (Fig. 30)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	13	35	*Eucalyptus largiflorens*
Herb	0.4	65	*Eleocharis acuta*, *Lachnagrostis filiformis*, *Eleocharis pusilla*, *Juncus flavidus*, **Lolium rigidum*, *Centipeda cunninghamii*, **Sonchus oleraceus*, *Damasonium minus*

Number of plots: 3

Mean number of species per plot (including unidentified): 28.7 (range 23–38)

Mean number of native species per plot: 18 (range 16–22)

Mean number of exotic species per plot: 10.7 (range 7–16)

Mean percentage of chenopod species per plot: 0

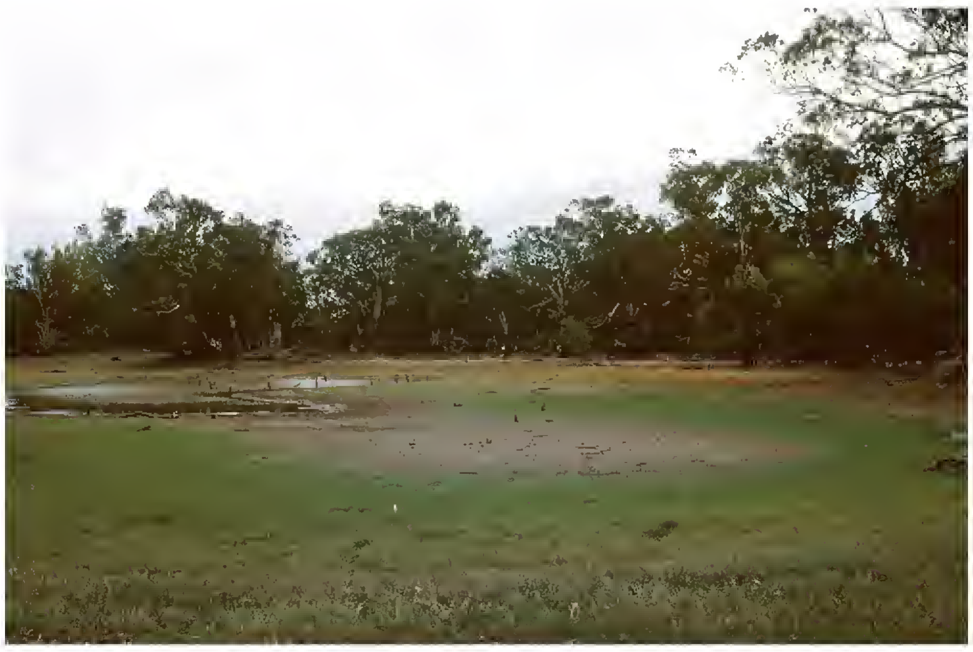

Fig. 29. Community 21, *Centipeda cunninghamii-Polygonum plebeium* herbland, near Kyalite (Edward River) in Section 4, with a mixture of species including *Centipeda cunninghamii, C. minima, Polygonum plebeium, Alternanthera denticulata, Psedognaphalium luteoalbum* and *Glinus lotoides*.

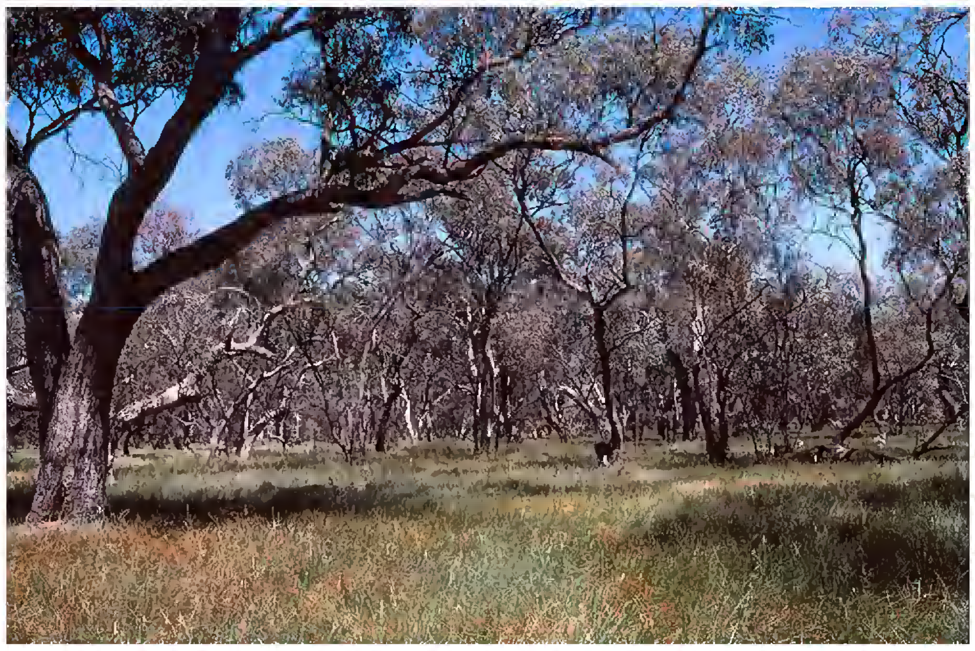

Fig. 30. Community 22, *Eucalyptus largiflorens-Eleocharis acuta* open-forest, near Torrumbarry in Section 4, showing the dense *Eleocharis acuta* understorey.

Black Box condition: 74% healthy, 26% unhealthy, 0 dead (n = 31)

Black Box regeneration: None in the plots

Mean grazing index (number of dropping clusters per 20 m): 2 (sheep 0.17, cattle 0.5, rabbit 0.67, kangaroo 0.67)

Distribution: NSW (1 plot) and Victoria (2 plots), in Section 4. Occurs in floodplain sites that are often flooded.

Notes: In some sites, at least, this community appeared to be the result of a recent increase in flooding frequency, which had brought about a change in the understorey vegetation but not yet the tree layer. In time, *Eucalyptus largiflorens* may be replaced by *E. camaldulensis* at these sites.

23. *Eucalyptus largiflorens – Muehlenbeckia florulenta – Chenopodium nitrariaceum* woodland (Fig. 31)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	12	30	*Eucalyptus largiflorens*, occasional *E. camaldulensis*
Tall shrub	6	15/0	*Acacia stenophylla*, sometimes forming dense stands but mostly absent
Mid shrub	1.3	25/0	*Muehlenbeckia florulenta, Chenopodium nitrariaceum*, sometimes absent
Low shrub	0.4	10/0	*Enchylaena tomentosa, Sclerolaena muricata, S. tricuspis*, or absent
Herb	0.1	25	**Hypochaeris glabra, *Hordeum murinum, Einadia nutans, *Vulpia myuros, Austrodanthonia caespitosa, Cotula australis, *Sonchus oleraceus, Solanum esuriale*

Number of plots: 19

Mean number of species per plot (including unidentified): 26.2 (range 6–43)

Mean number of native species per plot: 17.3 (range 3–28)

Mean number of exotic species per plot: 8.3 (range 0–17)

Mean percentage of chenopod species per plot: 17%

Black Box condition: 57% healthy, 32% unhealthy, 11% dead (n = 228)

Black Box regeneration: 216 per ha (1% <1 m, 41% 1–4 m, 58% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 8.53 (sheep 0.16, cattle 0.74, rabbit 4.89, kangaroo 2.68, emu 0.05)

Distribution: NSW (7 plots) and Victoria (12 plots), in Sections 4 (7 plots), 5 (10 plots) and 6 (2 plots east of the South Australian border). A common floodplain community in the inner parts of the Black Box zone.

24. *Eucalyptus largiflorens – Muehlenbeckia florulenta – Atriplex semibaccata* woodland (Fig. 32)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	12	20	*Eucalyptus largiflorens*, occasional *E. camaldulensis*
Tall shrub	8	5/0	*Acacia stenophylla*, but mostly absent
Mid shrub	1.5	15	*Muehlenbeckia florulenta*
Low shrub	0.4	10	*Enchylaena toentosa*
Herb	0.2	35	*Einadia nutans, Paspalidium jubiflorum, Atriplex semibaccata, *Sonchus oleraceus, *Hordeum murinum, Senecio spanomerus, Sporobolus mitchellii, *Hypochaeris glabra*

Number of plots: 13

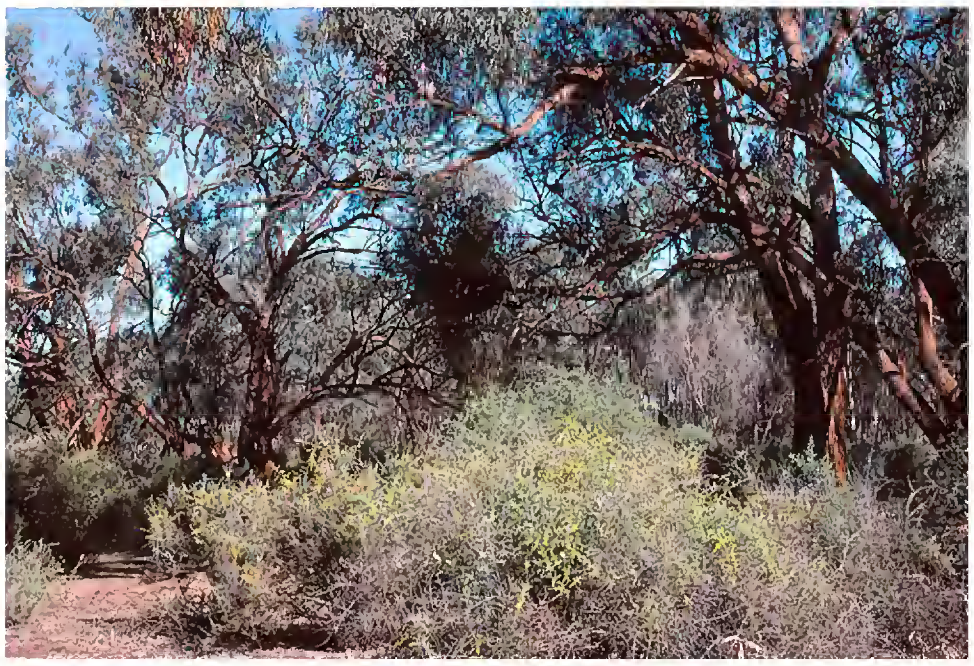

Fig. 31. Community 23, *Eucalyptus largiflorens-Muehlenbeckia florulenta-Chenopodium nitrariaceum* woodland, in Murray-Kulkyne Regional Park in Section 5, with an understorey dominated by *Chenopodium nitrariaceum.*

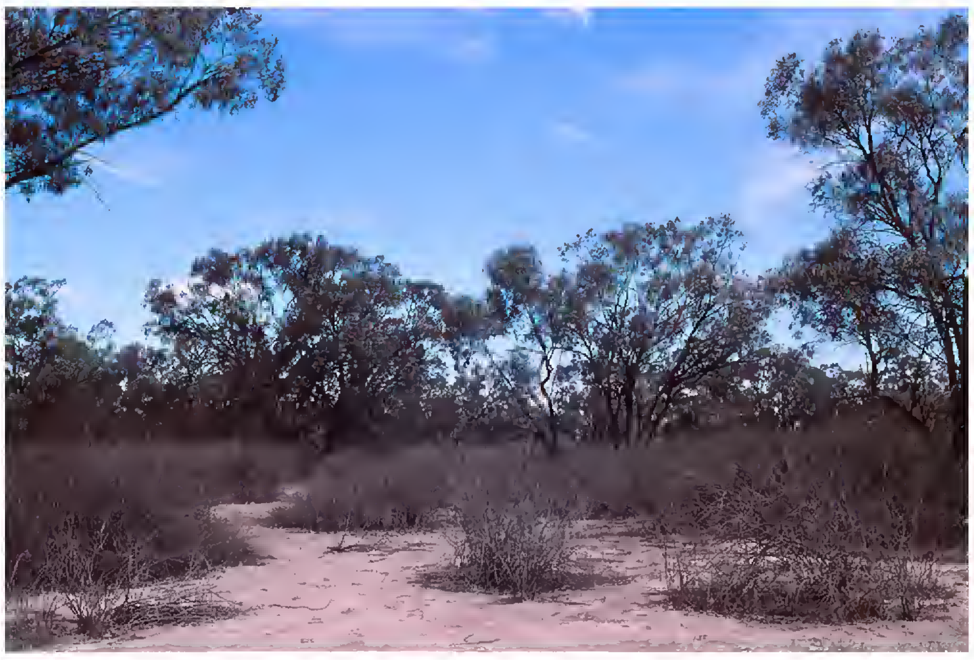

Fig. 32. Community 24, *Eucalyptus largiflorens-Muehlenbeckia florulenta-Atriplex semibaccata* woodland, at Katarapko Creek in Section 6, with an understorey dominated by *Muehlenbeckia florulenta.*

Mean number of species per plot (including unidentified): 21.7 (range 14–27)

Mean number of native species per plot: 14.3 (range 7–23)

Mean number of exotic species per plot: 7.3 (range 3–13)

Mean percentage of chenopod species per plot: 22%

Black Box condition: 70% healthy, 22% unhealthy, 8% dead (n = 120)

Black Box regeneration: 6 per ha (0 <1 m, 67% 1–4 m, 33% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 12.23 (sheep 0.62, cattle 0.46, horse 0.15, rabbit 10.19, pig 0.04, kangaroo 0.77)

Distribution: All plots in South Australia, in Sections 6 (5 plots) and 7 (8 plots). A common floodplain community in the inner parts of the Black Box zone. The South Australian equivalent of Community 23 from NSW and Victoria.

25. *Eucalyptus largiflorens – Melaleuca lanceolata – Allocasuarina luehmannii* woodland (Fig. 33)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	13	15	*Eucalyptus largiflorens*
Tall shrub	7	5	*Melaleuca lanceolata*, *Allocasuarina luehmannii*, *Hakea tephrosperma*
Low shrub	0.4	30	*Sclerolaena muricatus*
Herb	0.2	70	**Hordeum murinum*, **Vulpia myuros*, **Schismus barbatus*, *Austrostipa nodosa*, *Austrodanthonia caespitosa*, *Atriplex leptocarpa*, *Einadia nutans*, **Sisymbrium erysimoides*

Number of plots: 2

Mean number of species per plot (including unidentified): 21 (range 20–22)

Mean number of native species per plot: 11.5 (range 11–12)

Mean number of exotic species per plot: 9.5 (range 9–10)

Mean percentage of chenopod species per plot: 14%

Black Box condition: 70% healthy, 30% unhealthy, 0 dead (n = 20)

Black Box regeneration: None in the plots

Mean grazing index (number of dropping clusters per 20 m): 7.75 (sheep 4.5, cattle 0.75, rabbit 1.5, kangaroo 1)

Distribution: Both plots in NSW, in Thule State Forest in Section 4, where it was found in and beside Green Gully, which was the former course of the Murray before the uplift of the Cadell Fault (Bowler 1978).

Notes: This community appears to be a marginal floodplain remnant of an *Allocasuarina luehmannii* (Buloke) community that originally covered the adjacent rise but has been cleared except for a few remnant Buloke trees. Most of the original extent of Buloke vegetation on rises in Section 4 has long been cleared (Smith *et al.* 1943). In the sample plot in Green Gully itself there were many old dead *Eucalyptus camaldulensis* trees, indicating that it was formerly a River Red Gum community.

26. *Eucalyptus largiflorens – Melaleuca lanceolata – Atriplex rhagodioides* woodland (Fig. 34)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	9	10	*Eucalyptus largiflorens*
Tall shrub	7	50	*Melaleuca lanceolata*
Mid shrub	1.5	5	*Atriplex rhagodioides*
Low shrub	0.4	20	*Enchylaena tomentosa*, *Maireana brevifolia*
Herb	0.1	20	*Atriplex lindleyi*, **Sonchus oleraceus*, **Hordeum murinum*, *Disphyma crassifolium*, *Einadia nutans*, **Vulpia myuros*, *Crassula sieberiana*, **Reichardia tingitana*

Number of plots: 3

Mean number of species per plot (including unidentified): 25.7 (range 24–28)

Mean number of native species per plot: 17 (range 14–19)

Mean number of exotic species per plot: 8.7 (range 6–10)

Mean percentage of chenopod species per plot: 30%

Black Box condition: 43% healthy, 57% unhealthy, 0 dead (n = 30)

Black Box regeneration: None in the plots

Mean grazing index (number of dropping clusters per 20 m): 14.33 (sheep 6, rabbit 6, kangaroo 2.33)

Distribution: All plots in South Australia, in Section 6. Typically found in infrequently flooded sites on reddish, rather sandy soils.

27. *Eucalyptus largiflorens – Atriplex nummularia* open-woodland (Fig. 35)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	7	5/0	*Eucalyptus largiflorens* or absent
Shrub	1	15	*Atriplex nummularia*, *Rhagodia spinescens*, *Enchylaena tomentosa*, *Maireana pyramidata*
Herb	0.1	55	**Schismus barbatus*, **Vulpia myuros*, *Atriplex lindleyi*, **Medicago polymorpha*, *Brachyscome lineariloba*, **Hordeum murinum*, **Bromus rubens*, *Plantago drummondii*

Number of plots: 4

Mean number of species per plot (including unidentified): 32.3 (range 29–35)

Mean number of native species per plot: 21.5 (range 17–25)

Mean number of exotic species per plot: 10.3 (range 9–14)

Mean percentage of chenopod species per plot: 29%

Black Box condition: 70% healthy, 25% unhealthy, 5% dead (n = 20)

Black Box regeneration: None in the plots

Mean grazing index (number of dropping clusters per 20 m): 8 (sheep 4.5, cattle 0.13, rabbit 3.13, kangaroo 0.25)

Distribution: NSW (1 plot) and Victoria (3 plots), in Sections 5 (1 plot) and 6 (3 plots). Outer, less frequently flooded parts of the Black Box zone.

28. *Eucalyptus largiflorens – Atriplex rhagodioides* woodland (Fig. 36)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	8	15	*Eucalyptus largiflorens*
Shrub	1	30	*Atriplex rhagodioides*, *Enchylaena tomentosa*, some *Atriplex nummularia*
Herb	0.1	15	*Crassula colorata*, *Einadia nutans*, *Disphyma crassifolium*, **Sonchus oleraceus*, *Actinobole uliginosum*, *Calotis hispidula*, **Vulpia myuros*, **Schismus barbatus*

Number of plots: 11 (including 3 badly salt-affected plots not used for the description and statistics)

Mean number of species per plot (including unidentified): 22.8 (range 7–35)

Mean number of native species per plot: 17.5 (range 7–25)

Mean number of exotic species per plot: 5.3 (range 0–11)

Mean percentage of chenopod species per plot: 24%

Black Box condition: 53% healthy, 34% unhealthy, 13% dead (n = 85)

Black Box regeneration: 103 per ha (6% <1 m, 64% 1–4 m, 30% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 9.38 (sheep 1.13, horse 0.13, rabbit 7, kangaroo 1.13)

Distribution: All plots in South Australia, in Section 6. Outer, less frequently flooded parts of the Black Box zone. The South Australian equivalent of Community 27 from NSW and Victoria.

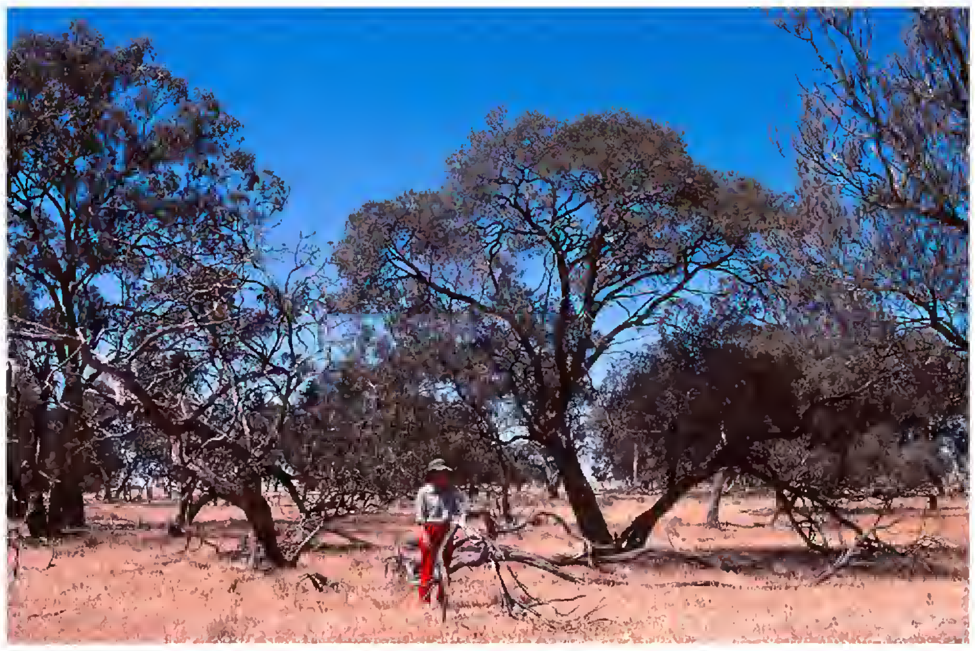

Fig. 33. Community 25, *Eucalyptus largiflorens-Melaleuca lanceolata-Allocasuarina luehmannii* woodland, in Thule State Forest in Section 4.

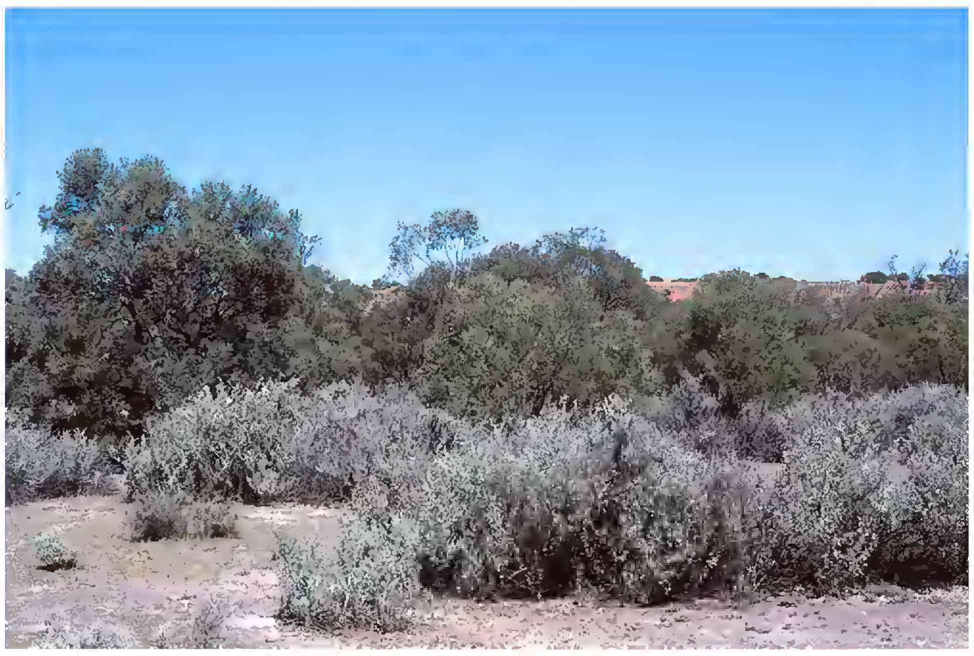

Fig. 34. Community 26, *Eucalyptus largiflorens-Melaleuca lanceolata-Atriplex rhagodioides* woodland, near Murtho in Section 6.

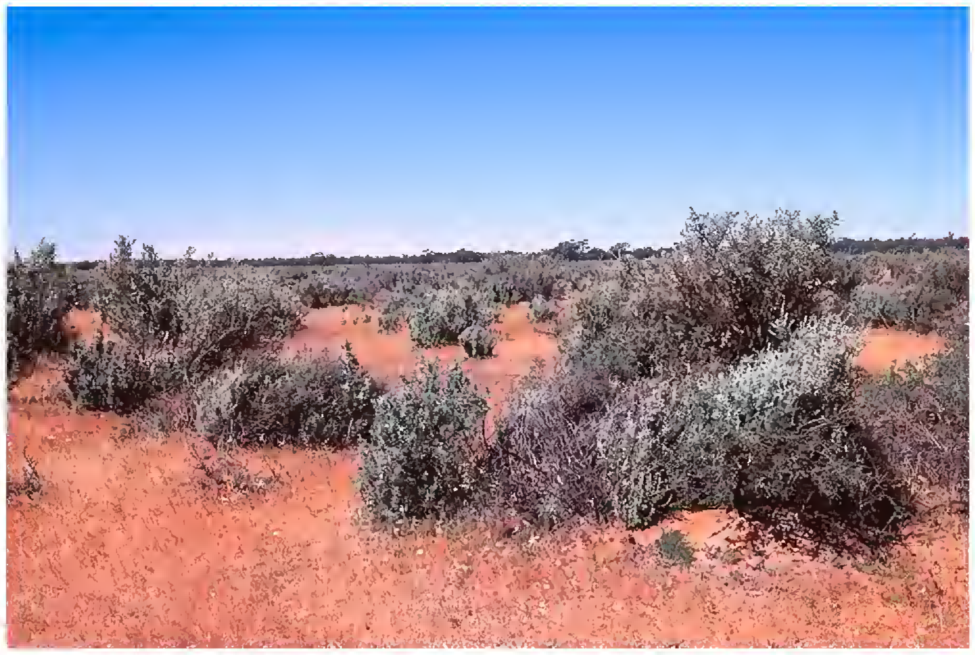

Fig. 35. Community 27, *Eucalyptus largiflorens- Atriplex nummularia* open-woodland, near Colignan in Section 5, with a shrub layer of *Atriplex nummularia* and *Rhagodia spinescens* and no tree layer.

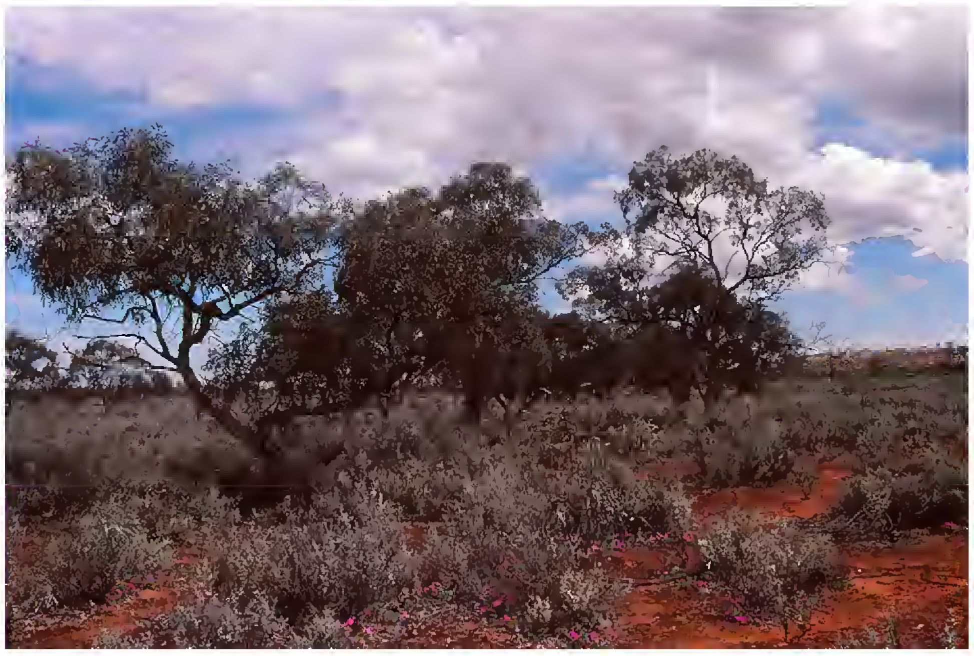

Fig. 36. Community 28, *Eucalyptus largiflorens- Atriplex rhagodioides* woodland, near Calperum in Section 6, with a shrub layer dominated by *Atriplex rhagodioides.*

29. *Chenopodium nitrariaceum – Muehlenbeckia florulenta* shrubland (Fig. 37)

Layer	Height (m)	Foliage cover (%)	Main species
Tall shrub	1.5	15	*Chenopodium nitrariaceum, Muehlenbeckia florulenta*
Low shrub	0.3	10	*Sclerolaena tricuspis*
Herb	0.1	40	*Sclerolaena brachyptera, *Vulpia myuros, Brachyscome lineariloba, Atriplex lindleyi, Calocephalus sonderi, *Bromus rubens, Atriplex leptocarpa, Einadia nutans*

Number of plots: 6

Mean number of species per plot (including unidentified): 30 (range 18–44)

Mean number of native species per plot: 23.3 (range 15–35)

Mean number of exotic species per plot: 6.5 (range 2–9)

Mean percentage of chenopod species per plot: 28%

Mean grazing index (number of dropping clusters per 20 m): 26.58 (sheep 4.17, cattle 0.17, rabbit 20.33, kangaroo 1.92)

Distribution: NSW (observed), Victoria (5 plots) and South Australia (1 plot), in Sections 4 (observed), 5 (4 plots) and 6 (2 plots). Found in the inner parts of the Black Box zone, typically in association with Community 23.

Notes: The dominant species may be either *Chenopodium nitrariaceum* or *Muehlenbeckia florulenta* or a mixture of the two.

30. *Muehlenbeckia florulenta – Tecticornia pergranulata* shrubland

Layer	Height (m)	Foliage cover (%)	Main species
Tall shrub	1.6	20	*Muehlenbeckia florulenta*, some *Atriplex rhagodioides*
Low shrub	0.3	15	*Tecticornia pergranulata*, *T. indica*, *Sclerolaena tricuspis*, *Enchylaena tomentosa*
Herb	0.2	25	*Atriplex lindleyi*, *A. leptocarpa*, *Sporobolus mitchellii*, *Atriplex semibaccata*, **Schismus barbatus*, *Einadia nutans*, **Hordeum murinum*, **Spergularia rubra*

Number of plots: 6

Mean number of species per plot (including unidentified): 26.3 (range 9–36)

Mean number of native species per plot: 16.3 (range 5–23)

Mean number of exotic species per plot: 10 (range 4–14)

Mean percentage of chenopod species per plot: 28%

Mean grazing index (number of dropping clusters per 20 m): 10.58 (sheep 0.33, rabbit 9.75, kangaroo 0.5)

Distribution: All plots in South Australia, in Sections 6 (4 plots) and 7 (2 plots). Found in saline sites, both on the floodplain and on the banks of saline water bodies. The South Australian equivalent of Community 29, which mainly occurs in Victoria and NSW.

Notes: Although this appears to be a natural community of saline depressions in the Black Box zone, four of the plots contained dead *Eucalyptus camaldulensis* trees (one of these also contained dead *E. largiflorens* trees), suggesting that they were former River Red Gum vegetation that had succumbed to increasing salinisation. The latter plots tended to have less *Muehlenbeckia* and more *Tecticornia*. The only eucalypt regeneration in the plots was a single *E. largiflorens* sapling.

31. *Atriplex vesicaria – Tecticornia triandra* shrubland

Layer	Height (m)	Foliage cover (%)	Main species
Shrub	0.4	20	*Atriplex vesicaria, Tecticornia triandra, Sclerolaena tricuspis*
Herb	0.1	35	**Vulpia myuros, Disphyma crassifolium, Brachyscome lineariloba, Bromus arenarius, Pogonolepis muelleriana, Actinobole uliginosum, Sclerolaena brachyptera, Crassula colorata*

Number of plots: 5

Mean number of species per plot (including unidentified): 21.6 (range 17–26)

Mean number of native species per plot: 15.8 (range 12–19)

Mean number of exotic species per plot: 5.6 (range 3–9)

Mean percentage of chenopod species per plot: 25%

Mean grazing index (number of dropping clusters per 20 m): 8.8 (sheep 3.6, cattle 0.1, horse 0.1, rabbit 3.7, kangaroo 1.3)

Distribution: NSW (2 plots), Victoria (2 plots) and South Australia (1 plot), in Sections 5 (1 plot at the far western end) and 6 (4 plots). Found in the outer, less frequently flooded parts of the Black Box zone, typically in association with Communities 27 and 28. *Atriplex vesicaria* shrubland was also once common in Section 4, but overgrazing has led to its replacement by *Nitraria billardierei* shrubland (Smith *et al.* 1943, Beadle 1948). The latter, highly derivative community was not sampled during this survey.

Notes: Varies from stands dominated by *Atriplex vesicaria* to stands dominated by *Tecticornia triandra*, although usually a mixture of both species. *Tecticornia triandra*, an unpalatable samphire, is presumably favoured by higher salinity levels and heavy grazing, compared with the much more palatable *Atriplex vesicaria*.

32. *Tecticornia pergranulata – T. indica* shrubland (Fig. 38)

Layer	Height (m)	Foliage cover (%)	Main species
Shrub	0.2	35	*Tecticornia pergranulata*, *T. indica*, *Sclerolaena tricuspis*
Herb	0.1	10	*Disphyma crassifolium*, *Atriplex lindleyi*, *Senecio glossanthus*, **Hordeum murinum*, **Parapholis incurva*, *Cressa australis*, **Bromus rubens*

Number of plots: 5

Mean number of species per plot (including unidentified): 12 (range 4–29)

Mean number of native species per plot: 7.6 (range 4–14)

Mean number of exotic species per plot: 4.2 (range 0–15)

Mean percentage of chenopod species per plot: 37%

Mean grazing index (number of dropping clusters per 20 m): 1.6 (sheep 0.1, cattle 0.1, rabbit 1.4)

Distribution: NSW (observed), Victoria (observed) and South Australia (plots), in Sections 4 to 8, but only sampled in Sections 6 (2 plots) and 7 (3 plots). Found in highly saline sites, often with salt crusting on the surface. Occurs in both the Black Box and River Red Gum zones, typically in depressions or on the edges of wetlands.

Notes: All plots were in sites that were formerly eucalypt communities, as indicated by the presence of dead trees and stumps. Although this community probably occurs naturally on the floodplain, the majority of occurrences are the result of increasing salinisation from irrigation activities. There was no eucalypt regeneration in any of the plots.

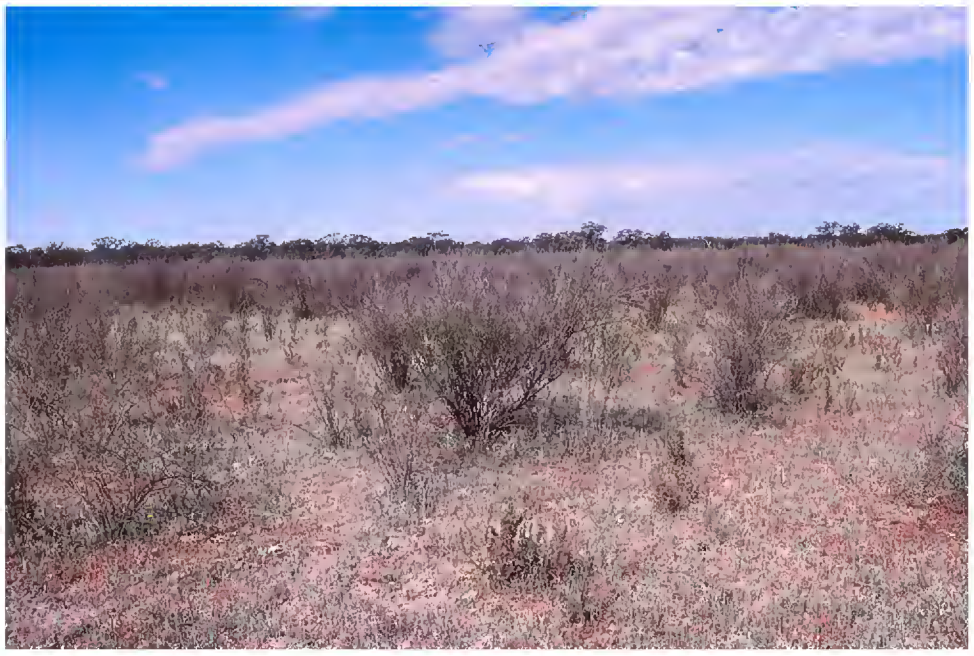

Fig. 37. Community 29, *Chenopodium nitrariaceum-Muehlenbeckia florulenta* shrubland, in Belsar Island State Forest in Section 5, dominated by *Muehlenbeckia florulenta.*

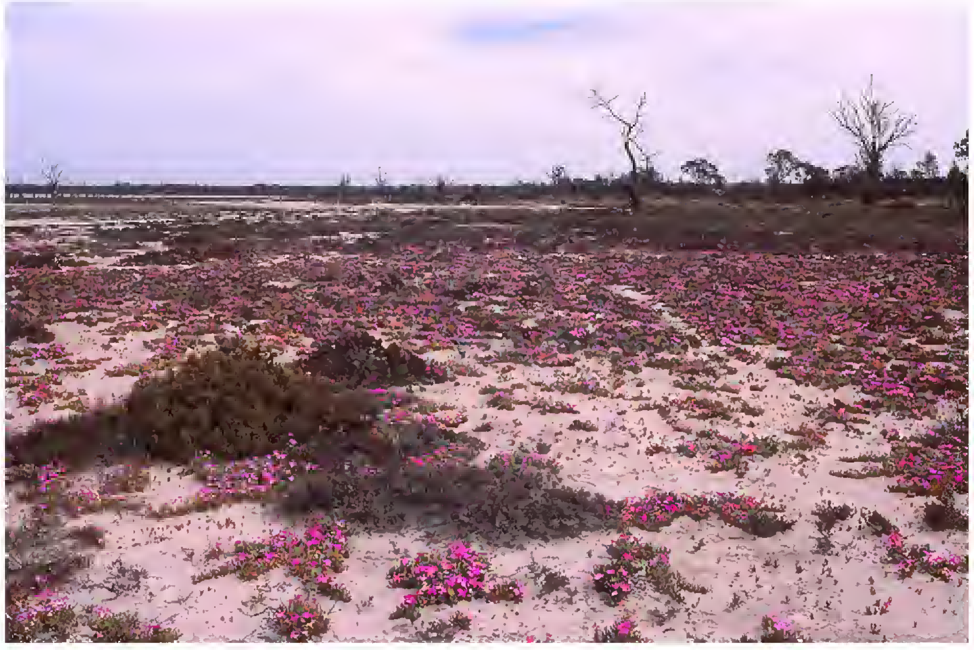

Fig. 38. Community 32, *Tecticornia pergranulata-T. indica* shrubland, near Waikerie in Section 7, dominated by *Tecticornia pergranulata* and *Disphyma crassifolium.*

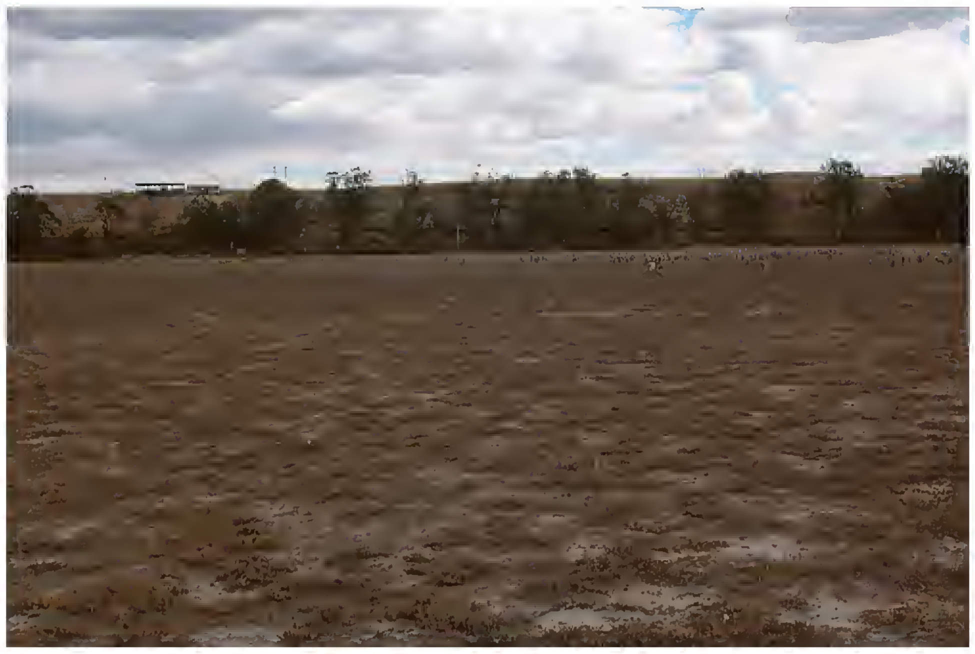

Fig. 39. Community 33, *Sporobolus mitchellii-Atriplex leptocarpa* grassland, at McBean Pound in Section 7.

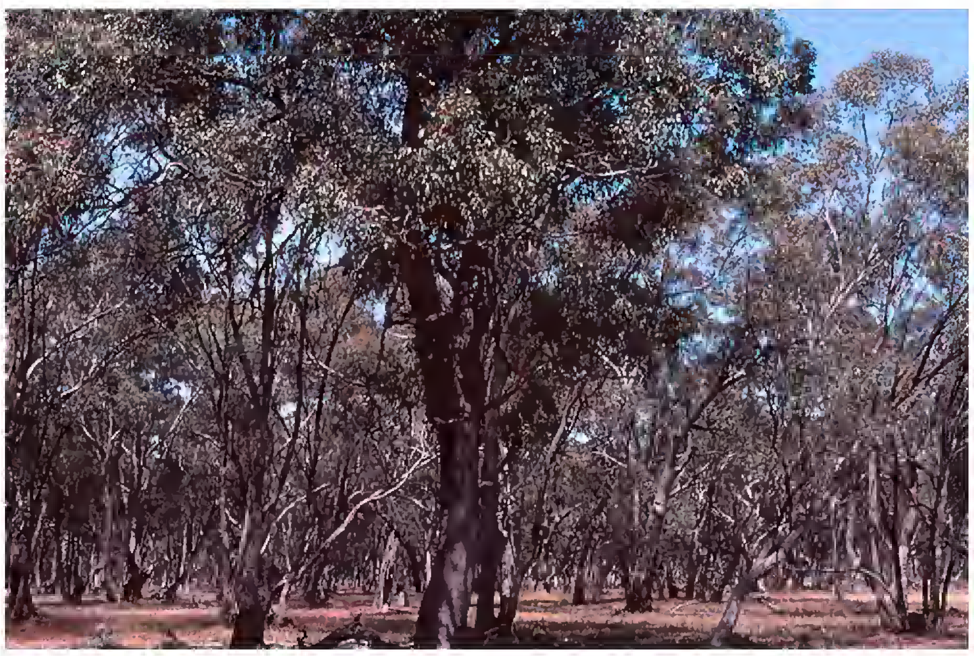

Fig. 40. Community 34, *Eucalyptus microcarpa* open-forest, on Ulupna Island in Section 2.

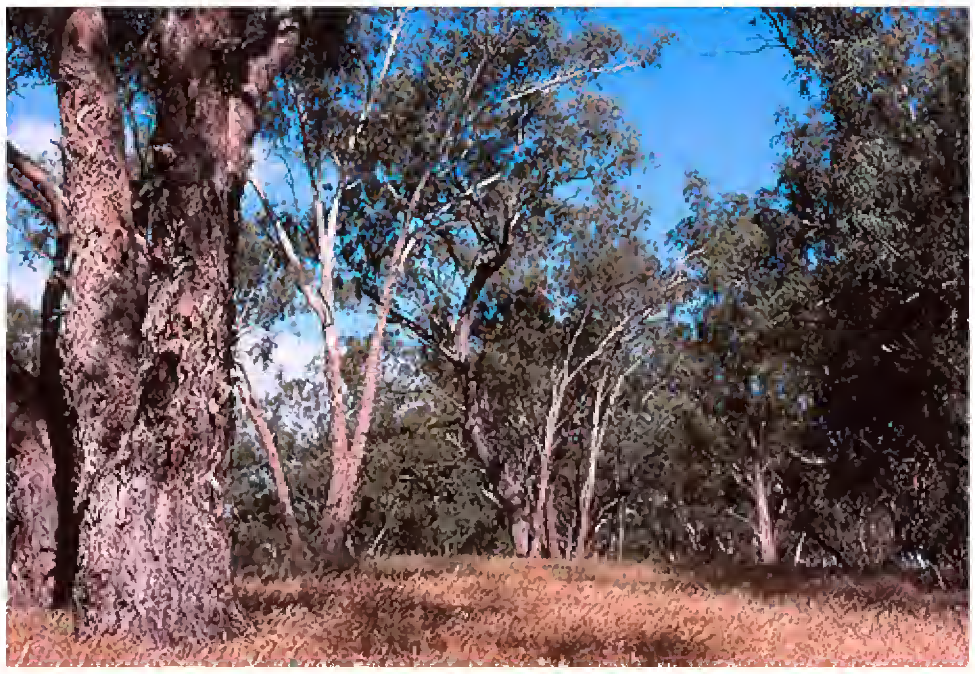

Fig. 41. Community 35, *Eucalyptus melliodora* woodland, near Yarrawonga Weir in Section 1.

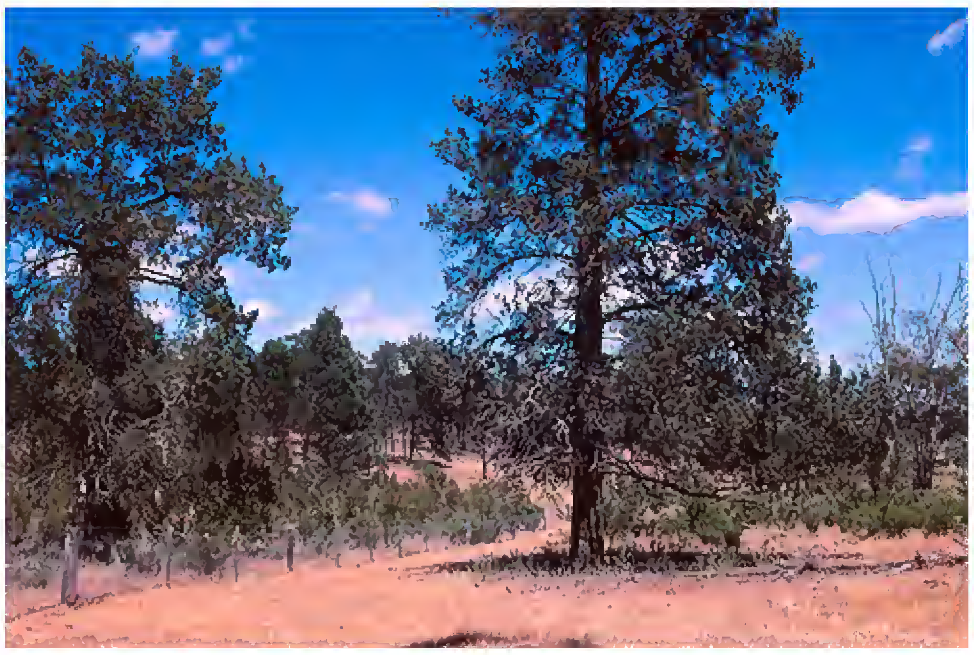

Fig. 42. Community 36, *Callitris glaucophylla* woodland, in Millewa State Forest in Section 3.

33. *Sporobolus mitchellii – Atriplex leptocarpa* grassland (Fig. 39)

Layer	Height (m)	Foliage cover (%)	Main species
Shrub	1	1	*Muehlenbeckia florulenta*
Tall herb	0.4	5	**Dittrichia graveolens*, *Cyperus gymnocaulos*, **Lactuca saligna*, **Cirsium vulgare*, *Sonchus hydrophilus*, **Aster subulatus*
Herb	0.1	45	*Sporobolus mitchellii*, *Atriplex leptocarpa*, **Spergularia rubra*, *Lachnagrostis filiformis*, **Sonchus oleraceus*, *Euchiton sphaericus*, **Asphodelus fistulosus*

Number of plots: 2

Mean number of species per plot (including unidentified): 13.5 (range 11–16)

Mean number of native species per plot: 7 (range 6–8)

Mean number of exotic species per plot: 6.5 (range 5–8)

Mean percentage of chenopod species per plot: 19%

Mean grazing index (number of dropping clusters per 20 m): 13.75 (sheep 13, cattle 0.5, kangaroo 0.25)

Distribution: Victoria (Ashwell 1987) and South Australia (plots), in Sections 6 (Ashwell 1987) and 7 (plots). *Sporobolus mitchellii* grasslands occur naturally in the Black Box zone, but may also result from clearing or overgrazing.

RISES WITHIN THE FLOODPLAIN

34. *Eucalyptus microcarpa* open-forest (Fig. 40)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	17	55	*Eucalyptus microcarpa*
Shrub	1.5	20/0	*Acacia acinacea* or absent
Herb	0.2	75	**Lolium perenne x rigidum*, *Carex inversa*, **Trifolium campestre*, **Bromus diandrus*, **B. madritensis*, **Trifolium striatum*, *Juncus flavidus*, *Einadia nutans*

Number of plots: 2

Mean number of species per plot (including unidentified): 37 (range 36–38)

Mean number of native species per plot: 15.5 (range 15–16)

Mean number of exotic species per plot: 21.5 (range 21–22)

Mean percentage of chenopod species per plot: 3%

Grey Box condition: 75% healthy, 22% unhealthy, 3% dead (n = 32)

Grey Box regeneration: 625 per ha (8% <1 m, 28% 1–4 m, 64% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 3.5 (kangaroo 3.5)

Distribution: Victoria, in Sections 2 (plots) and 3 (Chesterfield 1986). Apparently associated with higher ground that is rarely, if ever, flooded.

35. *Eucalyptus melliodora* woodland (Fig. 41)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	18	30	*Eucalyptus melliodora*, occasional *E. camaldulensis* and *Allocasuarina luehmannii*
Herb	0.2	85	**Bromus diandrus*, **Bromus hordeaceus*, **Vulpia bromoides*, **V. myuros*, **Trifolium arvense*, **T. campestre*, *Austrostipa nodosa*, **Lolium perenne x rigidum*

Number of plots: 4

Mean number of species per plot (including unidentified): 31.8 (range 24–44)

Mean number of native species per plot: 12.8 (range 8–18)

Mean number of exotic species per plot: 18.8 (range 12–26)

Mean percentage of chenopod species per plot: 3%

Yellow Box condition: 100% healthy, 0 unhealthy, 0 dead (n = 40)

Yellow Box regeneration: 56 per ha (0 <1 m, 56% 1–4 m, 44% >4 m)

Mean grazing index (number of dropping clusters per 20 m): 18.75 (cattle 2.13, rabbit 15, kangaroo 1.63)

Distribution: NSW (3 plots) and Victoria (1 plot), in Sections 1 (1 plot) and 3 (3 plots). Apparently associated with higher ground that is rarely, if ever, flooded. Soils tend to have a moderate to high sand content.

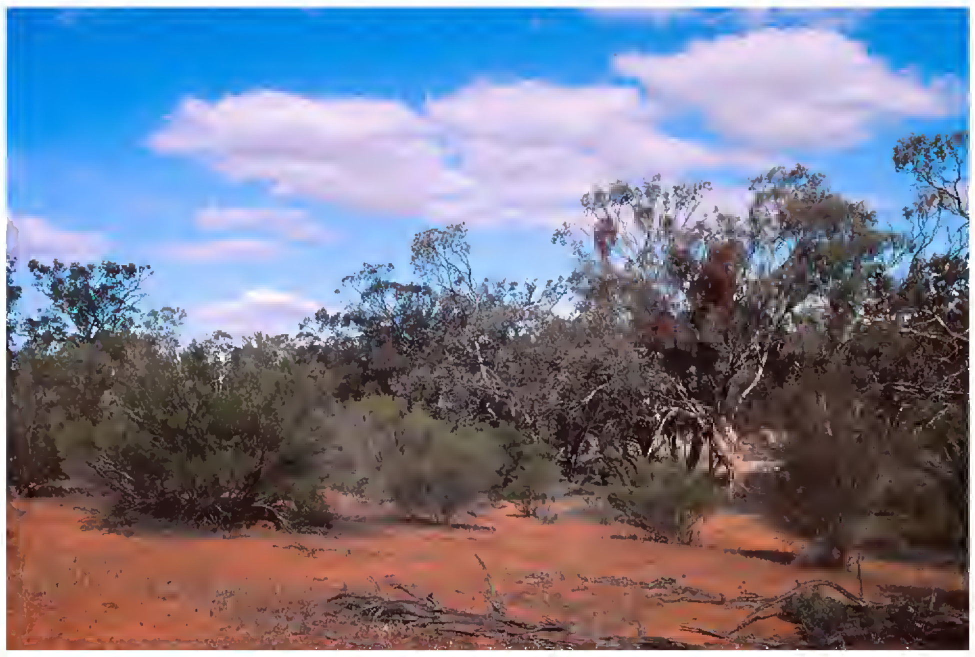

Fig. 43. Community 37, *Dodonaea viscosa-Callitris gracilis* shrubland, in Hattah-Kulkyne National Park in Section 5, dominated by *Dodonaea viscosa* ssp. *angustissima.*

36. *Callitris glaucophylla* woodland (Fig. 42)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	13	20	*Callitris glaucophylla*
Shrub	1.3	30/0	*Calytrix tetragona* or absent
Herb	0.2	60	**Vulpia myuros*, *Bromus rubens*, **B. diandrus*, *Pentaschistis airoides*, **Echium plantagineum*, **Trifolium arvense*, **Schismus barbatus*, **Hypochaeris glabra*

Number of plots: 3

Mean number of species per plot (including unidentified): 27.3 (range 18–33)

Mean number of native species per plot: 10 (range 1–15)

Mean number of exotic species per plot: 17.3 (range 16–19)

Mean percentage of chenopod species per plot: 4%

White Cypress Pine condition: 87% healthy, 3% unhealthy, 10% dead (n = 30)

White Cypress Pine regeneration: 58 per ha (29% <1 m, 71% 1–4 m, 0 >4 m)

Mean grazing index (number of dropping clusters per 20 m): 30.83 (cattle 3.17, rabbit 25, kangaroo 2.67)

Distribution: All plots in NSW, in Section 3. Found on reddish sandy soils on floodplain sand dunes, apparently above flood levels.

Notes: *Callitris gracilis* may also occur in this community but was not encountered at the few sites sampled by us. The plots were all on relatively well vegetated sand dunes. Many other dunes now have only a thin herb layer with few, if any, trees and shrubs, and are often badly eroded.

37. *Dodonaea viscosa – Callitris gracilis* shrubland (Fig. 43)

Layer	Height (m)	Foliage cover (%)	Main species
Tree	8	10/0	*Callitris gracilis* ssp. *murrayensis*, but mostly absent
Shrub	2	20	*Dodonaea viscosa*
Herb	0.1	30	**Vulpia myuros*, *Bromus rubens*, **Hypochaeris glabra*, **Pentaschistis airoides*, *Actinobole uliginosum*, *Austrodanthonia caespitosa*, *Myriocephalus rhizocephalus*, **Schismus barbatus*

Number of plots: 3

Mean number of species per plot (including unidentified): 23.7 (range 16–28)

Mean number of native species per plot: 14.3 (range 10–19)

Mean number of exotic species per plot: 8 (range 5–11)

Mean percentage of chenopod species per plot: 5%

Mean grazing index (number of dropping clusters per 20 m): 22.33 (rabbit 15, kangaroo 7.33)

Distribution: Victoria, in Sections 5 (plots) and 6 (Ashwell 1987). Found on reddish sandy soils on floodplain sand dunes, apparently above flood levels.

Notes: The original dominants in this community were probably *Callitris gracilis*, *Hakea leucoptera*, *Eremophila longifolia* and *Alectryon oleifolius* (Zimmer 1937), but the most common shrub encountered now is *Dodonaea viscosa* ssp. *angustissima*, a native ‘woody weed’. Many dunes are badly eroded and often the only vegetation is a sparse herb layer.

Appendix 2. Two-way classification of Murray riparian communities and common plant species

Communities numbered as in Appendix 1. * = exotic species, U = uncommon, M = moderately common, C = common, thick lines indicate a major division, thin lines indicate a minor division

Species	**Community**																																				
	36	35	34	16	4	19	14	13	3	10	6	5	2	22	1	20	21	11	7	8	9	15	17	25	29	23	33	30	24	26	18	12	37	28	31	27	32
Carex gaudichaudiana				U				U	U						M																						
Carex tereticaulis		U	U		M		U	M	M	M	U	C	U	U	U	U		U	U																		
*Cyperus eragrostis				U	M	U		M	M	U	U	U			U		U																				
Dichondra repens					U			U	M	U	U	U																									
Juncus amabilis					M	U		M	M		U	U	M		U			U																			
Persicaria prostrata					C	M	U	M	M		M				M	M	C	U	M																		
*Trifolium subterraneum				U	M			M	M	U	U	U																									
Eleocharis pusilla			U		U			U	M	M	M	M	M	M				U								U											
Juncus flavidus		U	M	U	U		M	M	U	M	M	U	U	M	U		U	U	U																		
*Leontodon taraxacoides	U	U	U		U	U	U	U	U	U	U	U		U	U			U	U																		
*Lolium rigidum		U			U			U	U	U	U	U		M										U													
Lythrum hyssopifolia					U			U	M	U	U	U	U	U		U																					
Acacia dealbata			U		M		U	U	U		U																										
Austrodanthonia duttoniana		U	U				M	U	M	M	M	U			U																						
*Bromus catharticus			U		U		U	U	U		U				U							U	U														
*Bromus hordeaceus	M	C	M	U	M		C	C	M	M	M	M	U	U				U						U													
Callitris glaucophylla	C																																				
*Carduus tenuiflorus	M	M	M		M			U	U		U	U	U																								
Carex inversa			M	U	M		U	M	M	M	M	U	U	M				U	U							U											
*Chondrilla juncea	M	M	M		U	U		U	U	U	U						U	U	U							U											
Elymus scaber	U	U	U		U		U	U	U	U		U																									
Eucalyptus melliodora		C						U																													
Eucalyptus microcarpa			C				U																														
Hemarthria uncinata					C			U	M		U	U																									
*Hordeum hystrix					U			M	U																												
*Hypochaeris radicata		U		M	C	M	U	C	M	M	U	M			U		U		U			U								U							
*Paspalum dilatatum		U			M		U	M	M	U	U	U										M	U														
Poa labillardierei		U		M	C	U	U	U	C	M	U	M							U																		
*Salix x rubens				C				U																													
*Trifolium angustifolium	U	U	M	U	U		U	M	M	U																											
*Trifolium arvense	M	M	U			U	U	U	U	U	U	U					U																				
*Trifolium campestre	U	M	M	U	M	M	U	M	M	M	U	M							U																		
*Trifolium cernuum	U	U	U		U	U		U	U	U	U	U																									
*Trifolium dubium			U		U			M	M	U		U																									
*Trifolium glomeratum	M	M	M	U	M	U	M	M	M	M	M	M		U			U	U	U			M				U											
*Trifolium striatum	U	M	M	U	U	U	U	M	U			U																									
*Trifolium tomentosum	U	M	M		U		U	U			U	U	U				U																				
*Vulpia bromoides	U	C	M	M	M	M		C	M	U	U	M						U																			
*Bromus madritensis			M		U			U	U	U	U													U													
*Echium plantagineum	M	M	M		U	M		M	U		M	U					M	U	U										U							U	
*Lolium perenne x rigidum		M	C	M	C	M	M	C	C	C	M	M	M		U		U	M	U			U	U	U	U	U											
Rumex brownii		M	M	U	M	M	U	M	M	M	M	M	M	M	M	U	M	U	M	U	U					U					M	M					
Alternanthera denticulata					U	M		U	M	U	M	U		U	C	M	M	U	M				U			U											
Eragrostis elongata		U				M	U		U		U								U													U					
*Phalaris species					M		M	U	U	M	M	U		U	U		U	U	U							U											
Senecio quadridentatus	M		U	U			U	U	M	U	C	M	U	U	U		U	U	U							U						U					
Centipeda minima												U			U		M		U																		
Paspalum distichum					U	U	U	U	M	U	U				M	U	U	U	U	M	M		U									U					
Pseudoraphis spinescens						U			M		U	U			C	C	U	U	U																		
Triglochin procera								U	U	U	U		U	U	M							U	M														
Hydrocotyle sibthorpioides				U	U			U	M		U	U																									
Ranunculus inundatus								U	U		U	M	C		M	U																					
Rumex crystallinus					U			U						U		U	M																				
Eleocharis acuta								U	M	U	M	M	C	C	C	C	U		M			U				U											

Species	**Community**																																				
	36	35	34	16	4	19	14	13	3	10	6	5	2	22	1	20	21	11	7	8	9	15	17	25	29	23	33	30	24	26	18	12	37	28	31	27	32
Myriophyllum crispatum/ verrucosum						U	U	U	U	U	U	M	M	U	M	U	U	U	U			U	U						U	U		U					
Persicaria hydropiper								U	U						U	C	U																				
Rorippa eustylis/laciniata									U	U	U	M	M		U	U	U		U																		
Stellaria angustifolia									U				M	U	M	U	U																				
**Solanum nigrum*					U		U	U	U		U	U			U		U	U	U	U		U							U			U					
Cyperus exaltatus									U	U	U	U			M		U	U	U	U	U		U														
Polygonum plebeium																	C			U																	
Azolla filiculoides							U	U					U	U	U				U		U	U	M														
Crassula helmsii															U							U	M														
Euchiton involucratus																						U	M														
Hydrocotyle verticillata																						M	C														
Juncus aridicola															U		U		U	U	U	M	C														
**Salix babylonica*							U	U										U				U	C														
Schoenoplectus validus																				U	M	U															
**Rumex crispus*				U	M			U	U										U		U	M	U														
**Anagallis arvensis*							U	U	U		U	U		U	U			U	U			U			U	U											
Centipeda cunninghamii					U	M	U	U	M	U	M	M	M	M	C	C	C	U	M	M			U		U	U											
Pratia concolor								U	U	U	U	M	U					U	U	U		U	M			U						U					
**Aster subulatus*				U	U	U			M	U	U	M	U	U	U	U	U	U	M	M	M	M	C				M	U				U					
Euchiton sphaericus	U					M			U	M	U	U	U	M	U			U	U			U			U	U	M										
**Cirsium vulgare*	U	M	M	M	M	U	M	M	M	M	M	M	M	U	U		U	M	M	M	M	M	M			U	M		U			U					
**Cynodon dactylon*				U	M	C	M	M	C	U	M	U	U		U		M	M	C	M	C	C	U			U		U	U		M	M					
Eucalyptus camaldulensis		U		M	C	M	C	C	C	C	C	C	C		C		M	C	C	C	C	C	U			U			U		U	C					
**Helminthotheca echioides*				U			U	U	U		U		M	M				U	U			M	M			U			U								
**Bromus diandrus*	C	C	C	U	U		C	C	M	U	M	M	U				U	U	U	U	M	M	U	U					U		U	M	U				
Eclipta platyglossa						U	U	U	M	U	M	M			U		U	M	M	M	U	U	U			U			U			U					
Phragmites australis				M			U	U	U		U				U			U	U	C	C	U	M									U					U
Typha domingensis/orientalis									U	U									U	U	M							U									
Epaltes australis											U				U		U	U	M	M			U						U								
Pseudognaphalium luteoalbum					U	U	M		M	U	M	U	U		U		M	U	M	M		M	U		U	U			U			U	U	U			
**Avena barbata*		U		U			M	M	U	U	M	U							U	U	U	M		U					U		M	U					
Chamaesyce drummondii		U					U	U	U	M	M	U	M		U		U	M	M	M						M		U	U			U					
**Conyza bonariensis*				M	M	U	U	U	M	U	U	U	U		U		U	U	M	M		U	U			U		M	U			M					
Lachnagrostis filiformis				M	M	C	M	M	C	M	M	M	C	C	M	M	M	M	M	M	U	M	M		M	U	M	U	U	U		U		U	U	U	
**Lactuca serriola*	U	U	U	U	U		M	U	M	M	M	M	U	M	U		U	M	M	M	U		U		U	U		U	U		M	U		M		U	
Paspalidium jubiflorum					M	U	M	U	M	U	C	M	U		M		U	M	C	M	M	U	U	U		U		U	C			C					
Wahlenbergia fluminalis			U	U	U	U	U	M	M	C	C	C	M		U		U	M	C	M	U	U	U		U	U	U		U		U	M					
**Marrubium vulgare*		U					U	U			U							U	U	U		U		U		U					U						
Amyema miquelii					U			U	U	U	U	U	U		U				U							M			U	U		U	U				
Brachyscome basaltica			U						U	U	U	M		U	U			U	U	U					U	U			U			U					
Marsilea drummondii					U				U	U	U	M	U	M				U	U					U	U	U			U			U					
Oxalis perennans	M	M	M	U	M		U	M	M	M	M	M	U		U			M	U					M	M	M								U			
**Sonchus asper*		U	M		M	M	M	M	M	U	M	M	M	M			M	M	U						U	U						U				U	
**Pentaschistis airoides*	M	M				U		U	U		U								U							U							M			U	
Stemodia florulenta															U			U	M	M		U				U		M				U					
**Taraxacum* species																			U			M	M									U					
**Xanthium orientale*																			M		U	M	U						U			U					
Cyperus gymnocaulos							U				U				U				M	C	C	C	U				M	U	U		C	M					
Picris squarrosa											U	U							M	M	M	M	U					U	U		M	M					
Sonchus hydrophilus							U		U			U	U				U		M	M	M	M	M				M	M	U			M					
Asperula gemella											U								U	U	M	M	M			U						U					
**Urospermum picroides*																		U	U	U	U	M				U		U	U			U	U				
Vittadinia cuneata							U			U	U							U	U	M	U	U				U			U		M	M		U			
**Euphorbia terracina*																			U	U	U	M	U						U		M	U					
Haloragis aspera							U	U		U	U							M	U	U			U			U			U			U					
**Phyla canescens*							M		U		U	U	U		U				U	U		U				U			U			M	U				
Senecio runcinifolius									U		U	U	U				U	U	M	U		U			U	U		U	U			U					
**Sonchus oleraceus*		M	M	U	U	M	M	M	M	M	M	M	M	M	U		U	C	M	M	U	M	M		M	M	M	M	M	C	M	M		M	U	M	U
Cotula australis				U	U				U	U	U		U	U			U	U	U			M			U	M		M	U	U		U				U	

Species	**Community**																																				
	36	35	34	16	4	19	14	13	3	10	6	5	2	22	1	20	21	11	7	8	9	15	17	25	29	23	33	30	24	26	18	12	37	28	31	27	32
**Hypochaeris glabra*	M	U	M			U	M	U	U	M	C	C	M	U			M	C	M	M	U	U			M	C		M	M	U	C	C	C	M		M	
**Bromus rubens*	C	M					M	U	U	U	U		U				M	C	M	M	U	U			M	C		M	M	U	C	C	C	M		M	
**Hordeum murinum*	U	U	M	U	U		M	M	U	M	M	U	U				U	U	U	U	U	M	U	C	M	C	U	M	M	C	U	M		M	M	M	M
**Medicago polymorpha*		U					M	U	U	U	U	U	U				M	U	U	U		M	U	M	M	U	U	U	U		U			U	U	M	U
Austrostipa species	M	M	U				U	U		U	U							U	U			U		M		U		U	U	U	M	M	M	M	U	M	
Austrodanthonia caespitosa	M	M	M		U		C	M	U	C	M	U						M	U			U		M	M	M		U				U	M	M	M	U	
**Vulpia myuros*	C	M	M	U	U	M	M	M	U	M	M	U	U				M	C	M			U		C	C	M		U	U	M		U	C	M	C	C	U
Atriplex lindleyi																			U			U			M	U		C	M	C		U		U	M	C	C
Brachyscome lineariloba										U								U	U			U			C	U			U	M		U		M	C	M	U
Calotis hispidula																		U	U						U	U		U				U		M	U	U	
Plantago cunninghamii group																		U	U		U				M	U		U	U			U		U	M	M	
**Spergularia rubra*										M	U								U	U		U			U	M	M	M	U			U			U	U	U
Wahlenbergia tumidifructa																			U						U	U			U	U			U	M	U		
Actinobole uliginosum	M																											U					M	M	M		
Atriplex nummularia																										U				U				U		C	
Atriplex rhagodioides																										U		M	U	M	U	U		C	U	U	
Atriplex vesicaria																																		U	C	U	
Bromus arenarius																									U										M	U	U
Bulbine semibarbata											U								U						U	U			U			U		M		U	
Calandrinia eremaea																										U			U	U		U	U	M	U	U	U
Crassula colorata	U												U				U		U						U	U		U	U	U			U	C	M	M	
Cressa australis																									M				U								M
Disphyma crassifolium																			U						M	U		M	U	M				C	C	M	C
**Mesembryanthemum nodiflorum*																									U			U	U					U	U		U
Pogonolepis muelleriana																									M					U		U		M	M	U	
Sclerolaena brachyptera																		U	U						C	U		U	U	U				U	M	M	
Sclerolaena tricuspis																									C	M		M	U	U				M	M	U	M
Senecio glossanthus																			U						M	U		U	M			U		M	M	M	M
Tecticornia indica																						U						M						U			M
Tecticornia pergranulata																				U					U			M	U	U							C
Tecticornia triandra																																		U	C	U	U
Tetragonia moorei																									U	U			U	U				U	U	M	U
Wahlenbergia gracilenta																									U	U							U	M	U	U	
Allocasuarina luehmannii																								C													
Chenopodium nitrariaceum							U											U	U						C	C			U			U				U	
Sclerolaena muricata							U											U	U					C		M		U	U						U		
Melaleuca lanceolata																								C						C							
**Brassica tournefortii*																			U			U				U		U	U	U	M	U	U	U			U
Callistemon brachyandrus																					U										C						
Dodonaea viscosa																				U									U				C				
**Silene* species													U								U	U			U	U			U	U	U	U	U	U		U	U
Atriplex leptocarpa											U							U	U	U		U		M	M	M	C	C	M	M		U					
Maireana brevifolia																			U								U	U	U	M	M						
Teucrium racemosum											U							U	U	U		U			U	U			U		U	U	U	U			
Daucus glochidiatus			U								U	U						U	U						U	U		U				U		M		U	
Rhagodia spinescens							U				U							U	U						U	U						U	U	U	U	M	U
**Schismus barbatus*	M			U			U		U		U	U						U	U					M		U		M	U	M			M	M	U	C	U
**Sisymbrium erisimoides*								U		U	U						U	U	U		U	U		M	U	U			U	U				U		U	U
Crassula sieberiana						M				U	U						U	U	U		U	U				U		U	M	M	U	U	M				U
Einadia nutans	M	M	M				U			M	U	U						M	U	U		M		M	M	C		M	C	M	M	M	U	C		U	U
Eucalyptus largiflorens							U				U	U		C	U			M	U				U	C		C			C	C		U	U	C		C	
**Lepidium africanum*							U	U		U		U	U				U		U	U		M	U	U	U	U	U	M	U	U	U	U			U		U
**Medicago minima*		U																U	U			U	U			U		U	U	U	U	U	U	M			
**Lamarckia aurea*																			U	U				U	U	U		U	U					U	U	U	
Muehlenbeckia florulenta																		M	U	M	M	M			C	C	U	C	C		C	C					
Senecio spanomerus																			U	M	U	U			U	U		M	M	U	U	M		M			U
Calocephalus sonderi																		U	U						M	U			U						U		

Species	**Community**																																				
	36	35	34	16	4	19	14	13	3	10	6	5	2	22	1	20	21	11	7	8	9	15	17	25	29	23	33	30	24	26	18	12	37	28	31	27	32
Vittadinia dissecta													U					M	U	U						U						M	M	U			
Acacia stenophylla											U				U				U	U			U			U			U			M					
Sporobolus mitchellii																			U	C		U	U		U	U	C	C	M			U					
Atriplex semibaccata/suberecta																		U	U	U		M			U	U		M	M	U	U	U					
Enchylaena tomentosa																		U	U	M	U	M			M	M		M	M	C	C	M	M	M		M	U
**Reichardia tingitana*																	U		M	M	U	M	U			U	U	M	M	M	M	M		M	U	M	U

Appendix 3. Plant species recorded in the survey plots

* =exotic species

Species	**State**			**River section**								**Vegetation zone**		
	NSW	**Vic**	**SA**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**RedGm**	**BlkBx**	**Rises**
FERNS														
Azollaceae														
Azolla filiculoides	N	V	S	1		3	4		6	7	8	G	B	
Azolla pinnata	N	V			2							G		
Marsileaceae														
Marsilea costulifera	N	V				3	4					G	B	
Marsilea drummondii	N	V	S		2	3	4	5	6	7		G	B	
CONIFERS														
Cupressaceae														
Callitris glaucophylla	N					3								R
Callitris gracilis ssp. *murrayensis*		V						5						R
DICOTYLEDONS														
Aizoaceae														
Carpobrotus modestus			S						6				B	
Disphyma crassifolium	N	V	S					5	6	7		G	B	
Glinus lotoides	N						4	5				G		
**Mesembryanthemum crystallinum*			S						6				B	
**Mesembryanthemum nodiflorum*	N		S						6				B	
Tetragonia moorei		V	S					5	6	7			B	
Amaranthaceae														
Alternanthera denticulata	N	V	S	1	2	3	4	5	6			G	B	
Alternanthera nodiflora		V	S					5		7		G		
**Alternanthera pungens*	N	V			2	3		5				G	B	R
Anacardiaceae														
**Schinus areira*			S							7	8	G		
Apiaceae														
**Ammi majus*			S								8	G		
**Berula erecta*			S								8	G		
Daucus glochidiatus	N	V	S		2		4	5	6	7		G	B	R
**Foeniculum vulgare*			S								8	G		
Hydrocotyle laxiflora	N			1										R
Hydrocotyle sibthorpioides	N	V		1	2	3						G		
Hydrocotyle verticillata			S								8	G		
Lilaeopsis polyantha			S								8	G		
Asteraceae														
Actinobole uliginosum	N	V	S			3		5	6				B	R
**Arctotheca calendula*	N	V	S	1		3	4	5	6	7	8	G	B	R
**Aster subulatus*	N	V	S	1	2	3	4	5	6	7	8	G	B	
Brachyscome basaltica var. *gracilis*	N	V	S		2	3	4	5	6	7		G	B	R
Brachyscome ciliaris var. *lanuginosa*		V	S					5	6	7		G	B	
Brachyscome lineariloba	N	V	S				4	5	6	7		G	B	
Calocephalus sonderi	N	V	S				4	5	6			G	B	
Calotis cuneifolia		V	S					5	6	7		G	B	
Calotis hispidula		V	S					5	6	7		G	B	
Calotis scabiosifolia	N						4					G	B	
Calotis scapigera	N	V	S	1	2	3	4	5		7		G	B	
**Carduus tenuiflorus*	N	V		1	2	3	4					G		R
**Carthamus lanatus*		V	S					5		7	8	G		
**Centaurea melitensis*	N	V					4	5				G	B	R
Centipeda cunninghamii	N	V	S	1	2	3	4	5	6	7		G	B	
Centipeda minima	N	V			2		4	5	6			G		
**Chondrilla juncea*	N	V		1	2	3	4	5				G	B	R
Chrysocephalum apiculatum			S						6			G		
**Cirsium vulgare*	N	V	S	1	2	3	4	5	6	7	8	G	B	R
**Conyza bonariensis*	N	V	S	1	2	3	4	5	6	7		G	B	
Cotula australis	N	V	S	1	2	3	4	5	6	7	8	G	B	
**Cotula bipinnata*	N	V					4		6			G	B	
**Cotula coronopifolia*		V	S				4		6	7	8	G	B	
Craspedia variabilis	N	V		1		3	4					G		
Cymbonotus lawsonianus	N	V					4	5				G	B	
**Dittrichia graveolens*	N	V	S		2			5	6	7		G	B	
Eclipta platyglossa	N	V	S	1	2	3	4	5	6	7	8	G	B	
Epaltes australis	N	V	S				4	5	6	7		G	B	
Euchiton gymnocephalus	N	V		1	2	3	4					G		

Species	**State**			**River section**								**Vegetation zone**		
	NSW	**Vic**	**SA**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**RedGm**	**BlkBx**	**Rises**
Euchiton involucratus			S								8	G		
Euchiton sphaericus	N	V	S		2	3	4	5	6	7		G	B	R
**Gamochaeta* species	N	V		1	2							G		
**Gazania* species		V	S					5	6			G		
**Hedypnois rhagadioloides*	N	V					4	5				G		R
Helichrysum rutidolepis		V		1								G		
**Helminthotheca echioides*	N	V	S			3	4			7	8	G	B	
**Hypochaeris glabra*	N	V	S		2	3	4	5	6	7		G	B	R
**Hypochaeris radicata*	N	V	S	1	2	3	4		6	7	8	G	B	R
Isoetopsis graminifolia	N	V	S					5	6				B	
**Lactuca saligna*	N	V	S	1	2	3	4			7		G	B	
**Lactuca serriola*	N	V	S	1	2	3	4	5	6	7		G	B	R
**Leontodon taraxacoides*	N	V		1	2	3	4					G	B	R
Minuria cunninghamii			S						6				B	
Myriocephalus rhizocephalus		V						5					B	
Olearia pimeleoides			S						6				B	
Picris squarrosa	N	V	S				4	5	6	7	8	G	B	
Pogonolepis muelleriana	N	V	S					5	6			G	B	
Polycalymma stuartii		V	S					5	6	7		G	B	R
Pseudognaphalium luteoalbum	N	V	S	1	2	3	4	5	6	7		G	B	R
Pycnosorus pleiocephalus		V	S						6				B	
**Reichardia tingitana*	N	V	S					5	6	7	8	G	B	
Rhodanthe corymbiflora	N	V					4	5	6			G	B	
Rhodanthe stuartiana	N	V	S						6				B	
**Scorzonera laciniata*	N	V					4					G		
Senecio cunninghamii	N	V	S				4		6			G		
Senecio glossanthus	N	V	S				4	5	6	7		G	B	
**Senecio pterophorus*			S							7	8	G		
Senecio quadridentatus	N	V	S	1	2	3	4	5	6			G	B	R
Senecio runcinifolius	N	V	S		2	3	4	5	6	7		G	B	
Senecio spanomerus	N	V	S					5	6	7	8	G	B	
Solenogyne dominii	N	V			2	3						G		R
**Sonchus asper*	N	V		1	2	3	4	5	6			G	B	R
Sonchus hydrophilus	N	V	S				4	5	6	7	8	G	B	
**Sonchus oleraceus*	N	V	S	1	2	3	4	5	6	7	8	G	B	R
**Taraxacum* species			S							7	8	G		
Triptilodiscus pygmaeus		V			2							G		
**Urospermum picroides*		V	S					5	6	7	8	G	B	R
Vittadinia cervicularis var. *cervicularis*	N	V	S				4	5	6			G	B	
Vittadinia cuneata	N	V	S				4	5	6	7	8	G	B	
var. *cuneata*														
var. *hirsuta*														
Vittadinia dissecta	N	V	S				4	5	6	7		G	B	R
Vittadinia gracilis	N	V			2		4	5	6			G	B	
**Xanthium occidentale*		V						5				G		
**Xanthium orientale*	N		S						6	7	8	G	B	
**Xanthium spinosum*	N	V	S				4	5		7	8	G		
Xerochrysum bracteatum	N						4	5	6			G	B	
Boraginaceae														
**Amsinckia calycina*	N					3								R
**Echium plantagineum*	N	V	S	1	2	3	4	5	6			G	B	R
**Heliotropium curassavicum*			S						6	7		G	B	
Omphalolappula concava		V	S						6				B	
Plagiobothrys elachanthus		V						5					B	
Brassicaceae														
**Alyssum linifolium*		V	S						6				B	
**Brassica tournefortii*		V	S					5	6	7	8	G	B	R
**Capsella bursa-pastoris*	N					3	4					G	B	
**Carrichtera annua*			S							7		G	B	
**Lepidium africanum*	N	V	S			3	4	5	6	7	8	G	B	
**Lepidium bonariense*			S							7		G		
Pachymitus cardaminoides		V						5				G		
**Rapistrum rugosum*			S								8	G		
Rorippa eustylis group	N	V	S			3	4	5	6			G		
R. eustylis														
R. laciniata														
**Rorippa palustris*	N	V	S	1	2		4			7	8	G		
**Sisymbrium erysimoides*	N	V	S			3	4	5	6	7		G	B	

Species	**State**			**River section**								**Vegetation zone**		
	NSW	**Vic**	**SA**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**RedGm**	**BlkBx**	**Rises**
**Sisymbrium irio*	N	V	S			3	4		6			G	B	
**Sisymbrium officinale*	N					3						G		
**Sisymbrium orientale*	N	V					4		6			G	B	
Callitrichaceae														
Callitriche sonderi	N						4					G		
**Callitriche stagnalis*	N		S				4		6		8	G		
Campanulaceae														
Wahlenbergia communis	N	V			2	3	4					G	B	R
Wahlenbergia fluminalis	N	V	S	1	2	3	4	5	6	7		G	B	R
Wahlenbergia gracilienta	N	V	S					5	6				B	R
Wahlenbergia gracilis	N	V		1		3	4					G		
Wahlenbergia graniticola	N			1		3								R
Wahlenbergia luteola	N			1										R
Wahlenbergia multicaulis	N	V				3						G		
Wahlenbergia tumidifructa	N	V	S					5	6			G	B	R
Caryophyllaceae														
**Cerastium glomeratum*	N	V	S	1	2	3	4				8	G		
**Petrorhagia velutina*	N	V		1	2	3	4					G	B	R
Scleranthus minusculus		V						5						R
**Silene* species		V	S				4	5	6	7	8	G	B	R
**Spergularia diandra*			S						6			G	B	
**Spergularia rubra*	N	V	S		2	3	4	5	6	7	8	G	B	
Stellaria angustifolia	N	V			2	3	4					G	B	
**Stellaria media*	N				2		4					G		
Casuarinaceae														
Allocasuarina luehmannii	N						4						B	
Chenopodiaceae														
Atriplex eardleyae		V	S						6	7		G	B	
Atriplex conduplicata		V						5					B	
Atriplex leptocarpa	N	V	S				4	5	6	7		G	B	
Atriplex limbata			S							7			B	
Atriplex lindleyi	N	V	S					5	6	7		G	B	
Atriplex nummularia	N	V	S					5	6				B	
Atriplex pseudocampanulata		V						5					B	
Atriplex rhagodioides		V	S						6	7		G	B	
Atriplex semibaccata group	N	V	S				4	5	6	7	8	G	B	
A. semibaccata														
A. suberecta														
Atriplex spongiosa		V							6				B	
Atriplex stipitata			S							7		G		
Atriplex vesicaria	N	V	S						6				B	
**Chenopodium album*			S							7	8	G		
Chenopodium glaucum			S						6				B	
**Chenopodium murale*	N	V				3		5					B	R
Chenopodium nitrariaceum	N	V	S				4	5	6			G	B	
Dissocarpus biflorus		V	S					5	6				B	
Dysphania glomulifera		V						5				G		
Einadia nutans	N	V	S	1	2	3	4	5	6	7	8	G	B	R
Enchylaena tomentosa	N	V	S				4	5	6	7	8	G	B	R
Maireana appressa			S						6			G	B	
Maireana brevifolia			S						6	7		G	B	
Maireana enchylaenoides	N	V				3	4						B	R
Maireana pentagona		V	S					5	6			G	B	
Maireana pentatropis			S							7			B	
Maireana pyramidata		V	S						6				B	
Malacocera tricornis	N	V						5	6				B	
Osteocarpum species	N	V	S					5	6	7			B	
O. acropterum														
O. salsuginosum														
Rhagodia spinescens	N	V	S				4	5	6			G	B	R
Salsola kali	N		S				4		6	7		G	B	
Sclerolaena brachyptera	N	V	S					5	6	7		G	B	
Sclerolaena diacantha		V	S						6				B	
Sclerolaena muricata var. *muricata*	N	V	S				4	5	6	7		G	B	
Sclerolaena muricata var. *villosa*	N	V	S				4	5		7		G	B	
Sclerolaena obliquicuspis			S						6	7		G	B	
Sclerolaena patenticuspis		V							6				B	
Sclerolaena stelligera	N	V	S				4	5	6	7			B	

Species	**State**			**River section**								**Vegetation zone**		
	NSW	**Vic**	**SA**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**RedGm**	**BlkBx**	**Rises**
Sclerolaena tricuspis	N	V	S				4	5	6	7			B	
Suaeda australis			S						6	7			B	
Tecticornia indica			S						6	7		G	B	
Tecticornia pergranulata		V	S					5	6	7		G	B	
Tecticornia triandra	N	V	S					5	6	7			B	
Clusiaceae														
Hypericum gramineum	N	V		1	2	3	4					G		
Hypericum perforatum	N			1								G		
Convolvulaceae														
Calystegia sepium	N	V	S			3					8	G		
Convolvulus erubescens	N	V	S	1		3	4	5		7		G	B	R
Cressa australis		V	S					5	6	7			B	
Dichondra repens	N	V		1	2	3						G		
Crassulaceae														
Crassula colorata	N	V	S			3	4	5	6			G	B	R
Crassula decumbens		V					4						B	
Crassula helmsii			S						6		8	G		
Crassula peduncularis		V					4					G		
Crassula sieberiana	N	V	S		2	3	4	5	6	7		G	B	R
Cucurbitaceae														
**Citrullus lanatus*			S						6				B	
Cuscutaceae														
**Cuscuta* species	N		S				4		6			G		
Euphorbiaceae														
Chamaesyce drummondii	N	V	S	1	2	3	4	5	6	7		G	B	R
**Euphorbia peplus*		V				3						G		
**Euphorbia terracina*			S							7	8	G	B	
Phyllanthus lacunarius			S						6				B	
Fabaceae														
Acacia acinacea	N	V			2		4					G		R
Acacia dealbata	N	V		1	2	3	4					G		R
Acacia ligulata			S						6	7		G		
Acacia salicina	N	V					4	5				G		
**Acacia saligna*			S								8	G		
Acacia stenophylla	N	V	S				4	5	6	7		G	B	
Cullen australasicum			S								8	G		
Cullen pallidum		V						5						R
Glycine clandestina	N	V		1		3						G		R
Glycine tabacina	N			1								G		R
Glycyrrhiza acanthocarpa	N		S				4		6	7		G	B	
**Lathyrus angulatus*		V			2							G		
Lotus cruentus		V	S					5	6	7		G		R
**Medicago minima*	N	V	S			3	4	5	6	7		G	B	R
**Medicago polymorpha*	N	V	S		2	3	4	5	6	7	8	G	B	R
**Medicago truncatula*			S							7	8	G		
**Melilotus albus*			S								8	G		
**Melilotus indicus*	N		S						6	7	8	G		
Swainsona greyana			S							7		G		
Swainsona microphylla		V	S					5		7		G		R
Swainsona phacoides		V						5						R
**Trifolium angustifolium*	N	V		1	2	3	4					G		R
**Trifolium arvense*	N	V		1	2	3	4					G		R
**Trifolium campestre*	N	V		1	2	3	4					G		R
**Trifolium cernuum*	N	V		1	2	3	4					G		R
**Trifolium dubium*	N	V		1	2	3	4					G		R
**Trifolium glomeratum*	N	V	S	1	2	3	4				8	G	B	R
**Trifolium ornithopodioides*		V		1								G		
**Trifolium repens*	N	V	S	1	2	3	4				8	G		
**Trifolium striatum*	N	V		1	2	3	4					G		R
**Trifolium subterraneum*	N	V		1	2	3	4					G		
**Trifolium tomentosum*	N	V		1	2	3	4					G		R
**Vicia hirsuta*	N	V		1		3	4					G		
**Vicia monantha*			S							7		G		
**Vicia sativa*	N	V	S	1	2	3	4			7		G		R
ssp. *nigra*														
ssp. *sativa*														
**Vicia tetrasperma*	N					3						G		

Species	**State**			**River section**								**Vegetation zone**		
	NSW	**Vic**	**SA**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**RedGm**	**BlkBx**	**Rises**
Frankeniaceae														
Frankenia serpyllifolia	N		S					5	6				B	
Fumariaceae														
**Fumaria bastardii*			S							7	8	G		
**Fumaria capreolata*		V					4					G		
**Fumaria densiflora*		V						5					B	
**Fumaria muralis*	N						4					G		
Gentianaceae														
**Centaurium erythraea*		V			2							G		
**Centaurium tenuiflorum*		V		1								G		
Schenkia spicata		V		1				5				G	B	
Geraniaceae														
**Erodium cicutarium*	N	V	S			3	4	5		7			B	R
Erodium crinitum		V						5						R
Geranium retrorsum	N	V		1	2	3	4	5				G	B	
Geranium solanderi			S								8	G		
Goodeniaceae														
Goodenia fascicularis	N	V	S				4	5	6			G	B	R
Goodenia glauca	N	V	S				4	5	6	7		G	B	
Goodenia gracilis	N	V		1	2	3	4					G	B	
Goodenia heteromera		V						5				G		
Goodenia pusilliflora	N	V	S					5	6			G	B	
Haloragaceae														
Haloragis aspera	N	V	S	1	2		4	5	6	7		G	B	
**Myriophyllum aquaticum*			S								8	G		
Myriophyllum crispatum group	N	V	S	1	2	3	4		6		8	G	B	
M. crispatum														
M. verrucosum														
Lamiaceae														
Ajuga australis	N	V				3		5				G	B	R
**Lamium amplexicaule*		V					4					G		
Lycopus australis			S							7	8	G		
**Marrubium vulgare*	N	V	S	1		3	4	5		7	8	G	B	R
Mentha australis	N	V	S		2	3			6			G		
Mentha diemenica		V		1								G		
**Mentha pulegium*	N	V		1		3						G		
**Mentha x spicata*	N			1								G		
Teucrium racemosum	N	V	S				4	5	6	7		G	B	R
Linaceae														
Linum marginale		V			2							G		
Lobeliaceae														
Isotoma fluviatilis ssp. *australis*	N	V			2							G		
Isotoma tridens	N				2							G		
Lobelia pratioides	N						4					G		
Pratia concolor	N	V	S		2	3	4	5	6	7	8	G	B	
Loranthaceae														
Amyema miquelii	N	V	S	1	2	3	4	5	6	7		G	B	R
Lythraceae														
Lythrum hyssopifolia	N	V		1	2	3	4					G	B	
Malvaceae														
Malva preissiana			S							7			B	
Sida corrugata var. *angustifolia*	N	V				3	4	5	6			G	B	R
Sida corrugata var. *corrugata*	N	V				3	4						B	R
Sida trichopoda	N	V		1			4	5				G	B	
Menyanthaceae														
Nymphoides crenata	N	V				3	4					G		
Myoporaceae														
Eremophila divaricata	N	V	S					5	6	7			B	
Myoporum montanum			S							7	8	G		
Myrsinaceae														
**Anagallis arvensis*	N	V	S	1		3	4	5	6	7		G	B	
Myrtaceae														
Callistemon brachyandrus			S							7		G		
Calytrix tetragona	N					3								R
Eucalyptus camaldulensis	N	V	S	1	2	3	4	5	6	7	8	G	B	R
Eucalyptus largiflorens			S				4	5	6	7		G	B	R
Eucalyptus melliodora	N	V		1		3						G		R
Eucalyptus microcarpa		V			2		4					G		R

Species	**State**			**River section**								**Vegetation zone**		
	NSW	**Vic**	**SA**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**RedGm**	**BlkBx**	**Rises**
Melaleuca lanceolata	N		S				4		6				B	
Oleaceae														
**Fraxinus rotundifolia*			S								8	G		
Onagraceae														
Epilobium billardierianum	N	V		1		3	4					G	B	
Epilobium hirtigerum	N	V		1	2	3	4					G		
**Ludwigia peploides*	N	V	S	1	2	3	4		6			G		
Oxalidaceae														
Oxalis perennans	N	V	S	1	2	3	4	5	6			G	B	R
**Oxalis pes-caprae*			S								8	G		
Oxalis radicosa	N					3								R
Pittosporaceae														
Pittosporum angustifolium		V					4					G		
Plantaginaceae														
Plantago cunninghamii group	N	V	S					5	6	7		G	B	
P. cunninghamii														
P. drummondii														
P. turrifera														
Plantago debilis	N	V					4					G		
**Plantago lanceolata*	N	V		1			4					G		
Polygonaceae														
**Acetosella vulgaris*	N	V		1								G		
Muehlenbeckia florulenta	N	V	S				4	5	6	7	8	G	B	
Muehlenbeckia horrida ssp. *horrida*			S							7			B	
Persicaria decipiens	N	V	S	1	2	3	4		6		8	G		
Persicaria hydropiper	N	V		1	2	3						G		
Persicaria lapathifolia		V	S					5		7		G		
Persicaria prostrata	N	V	S	1	2	3	4	5	6			G		
**Polygonum aviculare*	N	V		1		3	4					G	B	
Polygonum plebeium	N	V	S		2		4	5		7		G		
Rumex bidens			S						6			G		
Rumex brownii	N	V	S	1	2	3	4	5	6	7		G	B	R
**Rumex crispus*	N	V	S	1	2					7	8	G		
Rumex crystallinus	N	V		1	2	3	4					G	B	
**Rumex pulcher*	N			1								G		
Portulacaceae														
Calandrinia calyptrata	N	V					4	5					B	
Calandrinia eremaea	N	V	S					5	6	7		G	B	R
Calandrinia volubilis	N	V	S					5	6				B	
Proteaceae														
Hakea leucoptera		V						5						R
Hakea tephrosperma	N						4						B	
Ranunculaceae														
Myosurus australis		V	S				4	5	6			G	B	
Ranunculus amphitrichus			S								8	G		
Ranunculus inundatus	N	V		1	2	3	4					G		
Ranunculus lappaceus	N	V			2	3	4					G		
**Ranunculus muricatus*	N	V	S	1	2	3	4				8	G		
Ranunculus pentandrus		V	S					5	6	7		G	B	
Ranunculus pumilio var. *politus*		V		1	2							G		
Ranunculus pumilio var. *pumilio*	N	V		1		3	4					G	B	
**Ranunculus sceleratus*	N	V			2		4					G	B	
Ranunculus sessiliflorus	N						4					G		
**Ranunculus trilobus*			S								8	G		
Rosaceae														
Acaena novae-zelandiae		V				3						G		
**Rosa rubiginosa*	N	V		1	2	3	4					G		
**Rubus fruticosus* spp. agg.		V			2	3						G		
Rubiaceae														
Asperula conferta	N	V						5				G	B	
Asperula gemella	N	V	S				4	5	6	7	8	G	B	
**Galium aparine*	N	V		1	2	3	4	5				G	B	
Salicaceae														
**Salix babylonica*	N	V	S	1			4		6		8	G		
**Salix x rubens*	N	V		1		3						G		
Santalaceae														
Exocarpos strictus	N	V				3	4					G	B	

Species	**State**			**River section**								**Vegetation zone**		
	NSW	**Vic**	**SA**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**RedGm**	**BlkBx**	**Rises**
Sapindaceae														
Dodonaea viscosa ssp. *angustissima*		V	S					5		7		G	B	R
Scrophulariaceae														
Gratiola peruviana	N	V	S		2						8	G		
**Kickxia spuria*		V		1								G		
Mimulus gracilis	N						4						B	
Mimulus repens			S						6	7			B	
**Orobanche minor*	N			1										R
Stemodia florulenta	N	V	S					5	6	7	8	G	B	
**Verbascum virgatum*	N		S		2	3					8	G		R
**Veronica peregrina*	N	V	S	1	2	3	4		6			G	B	
Solanaceae														
**Lycium ferocissimum*		V	S				4		6	7	8	G	B	
**Nicotiana glauca*			S							7		G		
Nicotiana velutina		V	S					5	6				B	
Solanum esuriale	N	V	S				4	5	6	7		G	B	
**Solanum nigrum*	N	V	S		2	3	4	5	6	7	8	G	B	
**Solanum pseudocapsicum*	N				2							G		
Urticaceae														
**Urtica urens*	N		S			3	4		6		8	G	B	R
Verbenaceae														
**Phyla canescens*	N	V	S				4	5	6	7	8	G	B	R
**Verbena bonariensis*	N	V		1		3						G		
**Verbena officinalis*		V			2			5				G		
**Verbena supina*	N	V						5	6			G		
Violaceae														
Viola betonicifolia ssp. *betonicifolia*	N	V		1		3						G		
Zygophyllaceae														
Zygophyllum ammophilum			S						6				B	
Zygophyllum aurantiacum			S							7		G		
Zygophyllum confluens			S						6				B	
Zygophyllum glaucum	N	V						5	6				B	
Zygophyllum iodocarpum		V							6				B	
MONOCOTYLEDONS														
Alismataceae														
**Alisma lanceolatum*			S								8	G		
Damasonium minus	N	V					4					G	B	
Anthericaceae														
Arthropodium minus	N	V			2		4					G		R
Dichopogon fimbriatus		V			2							G		
Tricoryne elatior	N	V		1	2							G		R
Arecaceae														
**Phoenix* species	N			1								G		
Asparagaceae														
**Asparagus officinalis*	N	V	S	1			4	5	6			G	B	
Asphodelaceae														
**Asphodelus fistulosus*			S		2			5	6	7	8	G	B	
Bulbine semibarbata	N	V	S				4	5	6	7		G	B	
Cyperaceae														
Bolboschoenus medianus			S						6	7		G		
Carex appressa		V	S	1							8	G		
Carex chlorantha	N			1								G		
Carex gaudichaudiana	N	V		1		3						G		
Carex inversa	N	V		1	2	3	4					G	B	R
Carex tereticaulis	N	V		1	2	3	4					G	B	R
**Cyperus eragrostis*	N	V		1	2	3	4					G		
Cyperus exaltatus	N	V	S	1	2	3	4	5	6	7		G		
Cyperus gunnii	N						4					G		
Cyperus gymnocaulos	N	V	S				4	5	6	7	8	G	B	
Eleocharis acuta	N	V	S	1	2	3	4	5	6		8	G	B	
Eleocharis pusilla	N	V		1	2	3	4					G	B	R
Fimbristylis aestivalis	N				2							G		
Isolepis cernua			S								8	G		
Isolepis inundata			S								8	G		
**Isolepis marginata*		V						5						R
Isolepis victoriensis	N			1								G		
Schoenoplectus validus			S							7	8	G		

Species	**State**			**River section**								**Vegetation zone**		
	NSW	**Vic**	**SA**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**RedGm**	**BlkBx**	**Rises**
Schoenus apogon	N					3						G		
Hydrocharitaceae														
Vallisneria australis	N		S						6			G		
Iridaceae														
**Romulea rosea*	N	V		1								G		
Juncaceae														
Juncus amabilis	N	V		1	2	3	4					G		
Juncus aridicola	N		S					5	6	7	8	G		
**Juncus articulatus*	N	V					4					G		
Juncus bufonius	N	V		1	2							G		
Juncus flavidus	N	V		1	2	3	4					G	B	R
Juncus holoschoenus	N					3						G		
Juncus ingens	N	V		1	2	3						G		
Juncus usitatus	N			1								G		
Juncus vaginatus	N			1								G		
Juncaginaceae														
Triglochin centrocarpa		V						5						R
Triglochin procera	N	V	S	1	2	3	4				8	G	B	
Triglochin striata			S								8	G		
Lomandraceae														
Lomandra collina	N					3								R
Lomandra multiflora ssp. *multiflora*	N			1								G		R
Orchidaceae														
Microtis unifolia		V				3						G		
Phormiaceae														
Dianella longifolia	N	V				3	4					G		R
Poaceae														
**Agrostis capillaris*	N			1								G		
Amphibromus fluitans		V			2							G		
Amphibromus nervosus	N	V		1	2	3	4					G	B	
Aristida jerichoensis	N			1										R
Austrodanthonia caespitosa	N	V	S	1	2	3	4	5	6	7	8	G	B	R
Austrodanthonia duttoniana	N	V		1	2	3	4					G		R
Austrodanthonia setacea		V				3		5				G	B	
Austrostipa species	N	V	S	1	2	3	4	5	6	7	8	G	B	R
A. drummondii														
A. nitida														
A. nodosa														
A. scabra ssp. *falcata*														
**Avena barbata*	N	V	S	1	2	3	4	5	6	7	8	G	B	R
**Avena fatua*	N	V		1	2	3						G		
**Avena sativa*		V			2							G		
**Briza maxima*		V		1								G		
**Briza minor*	N	V		1	2	3	4					G		R
**Bromus alopecuros*	N	V			2		4					G		
Bromus arenarius	N	V	S					5	6				B	
**Bromus catharticus*	N	V	S	1	2	3	4				8	G		R
**Bromus diandrus*	N	V	S	1	2	3	4	5		7	8	G	B	R
**Bromus hordeaceus*	N	V		1	2	3	4					G	B	R
**Bromus madritensis*	N	V		1	2	3	4					G	B	R
**Bromus rubens*	N	V	S	1		3	4	5	6	7	8	G	B	R
Chloris truncata	N			1	2		4					G	B	
**Cynodon dactylon*	N	V	S	1	2	3	4	5	6	7	8	G	B	
**Cynosurus echinatus*	N	V		1								G		R
Deyeuxia quadriseta	N	V		1	2	3	4					G	B	R
Dichelachne micrantha		V		1	2							G		
Echinochloa colona	N						4					G		
**Echinochloa crus-galli*	N	V				3						G		
**Ehrharta erecta*	N	V			2	3						G		
**Ehrharta longiflora*	N		S				4			7		G		
**Elymus repens*	N	V	S		2		4		6			G		
Elymus scaber	N	V		1	2	3	4					G		R
Enneapogon avenaceus		V						5						R
Enteropogon acicularis	N	V			2		4	5				G	B	
Eragrostis australasica		V	S					5	6	7		G	B	
Eragrostis brownii	N	V		1								G		
Eragrostis dielsii			S							7		G		
Eragrostis elongata	N	V	S	1	2	3	4	5	6			G		R

Species	**State**			**River section**								**Vegetation zone**		
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Eragrostis lacunaria		V	S					5	6	7		G	B	
Eragrostis parviflora		V			2							G		
Eulalia aurea		V		1								G		
**Festuca arundinacea*			S								8	G		
Hemarthria uncinata	N	V		1	2	3						G		
**Holcus lanatus*	N	V		1		3						G		
**Hordeum hystrix*	N	V		1	2							G		
**Hordeum marinum*	N	V	S			3	4		6	7		G	B	
**Hordeum murinum*	N	V	S	1	2	3	4	5	6	7	8	G	B	R
Isachne globosa		V		1								G		
Lachnagrostis filiformis	N	V	S	1	2	3	4	5	6	7	8	G	B	
**Lamarckia aurea*	N	V	S				4		6	7		G	B	
**Lolium multiflorum*	N			1								G		
**Lolium perenne x rigidum*	N	V	S	1	2	3	4	5		7	8	G	B	R
**Lolium rigidum*	N	V		1	2	3	4					G	B	R
Microlaena stipoides	N	V		1								G		
**Panicum coloratum*	N						4		6			G		
Panicum effusum	N		S	1		3				7		G		R
**Parapholis incurva*	N		S						6	7			B	
Paspalidium jubiflorum	N	V	S	1	2	3	4	5	6	7		G	B	
**Paspalum dilatatum*	N	V	S	1	2	3	4				8	G		R
Paspalum distichum	N	V	S	1	2	3	4	5	6	7		G		
**Pennisetum clandestinum*	N		S	1							8	G		
**Pentaschistis airoides*	N	V		1	2	3		5				G	B	R
**Phalaris* species	N	V		1	2	3	4	5				G	B	
**P. minor*														
**P. paradoxa*														
Phragmites australis	N	V	S	1		3	4		6	7	8	G	B	
**Poa annua*		V	S	1							8	G		
Poa labillardierei	N	V		1	2	3	4	5				G		R
**Poa pratensis*	N			1								G		
Poa sieberiana	N				2	3						G		R
**Polypogon monspeliensis*	N	V	S	1	2		4		6	7		G	B	
Pseudoraphis spinescens	N	V	S	1	2	3	4	5	6			G		
**Rostraria cristata*	N	V	S			3		5		7		G	B	
**Rostraria pumila*			S						6				B	
**Schismus barbatus*	N	V	S		2	3	4	5	6	7		G	B	R
**Setaria pumila*		V		1	2							G		
Sporobolus mitchellii		V	S					5	6	7		G	B	
**Triticum aestivum*		V	S					5		7		G		
**Vulpia bromoides*	N	V		1	2	3	4					G		R
**Vulpia myuros*	N	V	S	1	2	3	4	5	6	7	8	G	B	R
Walwhalleya proluta	N	V		1			4					G		
Potamogetonaceae														
Potamogeton crispus	N		S						6	7		G		
Potamogeton tricarinatus	N	V	S			3	4	5	6	7		G		
Typhaceae														
Typha species	N	V	S			3	4		6	7	8	G	B	
T. domingensis														
T. orientalis														

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A conceptual model of the species composition of the original riparian rainforest of the Clarence River Floodplain, New South Wales

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Abstract: The riparian rainforest on the streamside levees of the coastal floodplain of the Clarence River on the North Coast of New South Wales was cleared during the 1860s by small landholders seeking fertile land. Only three small remnants remain. Using a combination of historical species lists, corner trees from surveyors' portion plans, habitat information and the NSW Scientific Committee's (1999) determination for lowland rainforest on floodplain a conceptual model of the original distribution of rainforest suballiances on the levees of the Clarence River coastal floodplain is proposed.

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Introduction

Before European settlement the banks of the coastal floodplain of the Clarence River in northern New South Wales (lat. 29.5˚S, long. 153.2˚E) (Figure 1) were vegetated by a band of rainforest that was known colloquially as 'brush' (Hodgkinson 1845, Rose 2012). In 1839, The Deputy Surveyor-General, Captain Perry onboard one of the first vessels to enter the Clarence River noted that:

> *owing to the denseness of the brush on the banks, no part of the country could be seen from the deck of the vessel, but was completely screened by a mass of most luxuriant vegetation: the stems of gigantic trees, covered with climbing plants of various descriptions, and which fell down in graceful festoons from the upper branches, produced an effect observable only in a region fresh from the hand of nature* (Lang 1847 p. 40)

J D Lang was seeking land for Scottish immigrants and Commissioner Fry reported to him that on the lower 20 miles (32 km) that:

> *the immediate borders of the stream being covered with a dense impervious brush* (Lang 1847 p.52)

and that for the next 30 miles (48km) the land:

> *becomes more elevated, more open, and of infinitely better description ....., a belt of brush varying in width from one to four hundred yards* (91–366m) *fringing the stream all the way up* (Lang 1847 p. 52)

The first Europeans to move into the Clarence Valley were cedar getters and graziers who mainly left the riparian rainforest undisturbed. The cedar getters only selectively removed the valuable red cedar from the rainforest; most of the easy to cut cedar exhausted by 1842 (Vader 1987 p.94). The impenetrable rainforest was of no use to the grazier (Lang 1847, Stubbs 1996 p. 124) but changes to the land laws (The Order in Council of 1847 followed by the *Crown Lands Alienation Act 1861)* enabled farmers to obtain smaller blocks (Stubbs 1996). The 'brush' forest blocks along the banks of the Clarence River were sought after due to their fertile soil. Due to its luxuriant nature the 'brush' was not possible to burn and it could only be cleared by cutting down the large trees with an axe. This was hard work and would take a week to clear an acre (4,000 m^2). Virtually none of the timber was sold, but merely allowed to dry for about a year and then burnt. In the meantime the settlers planted maize in between

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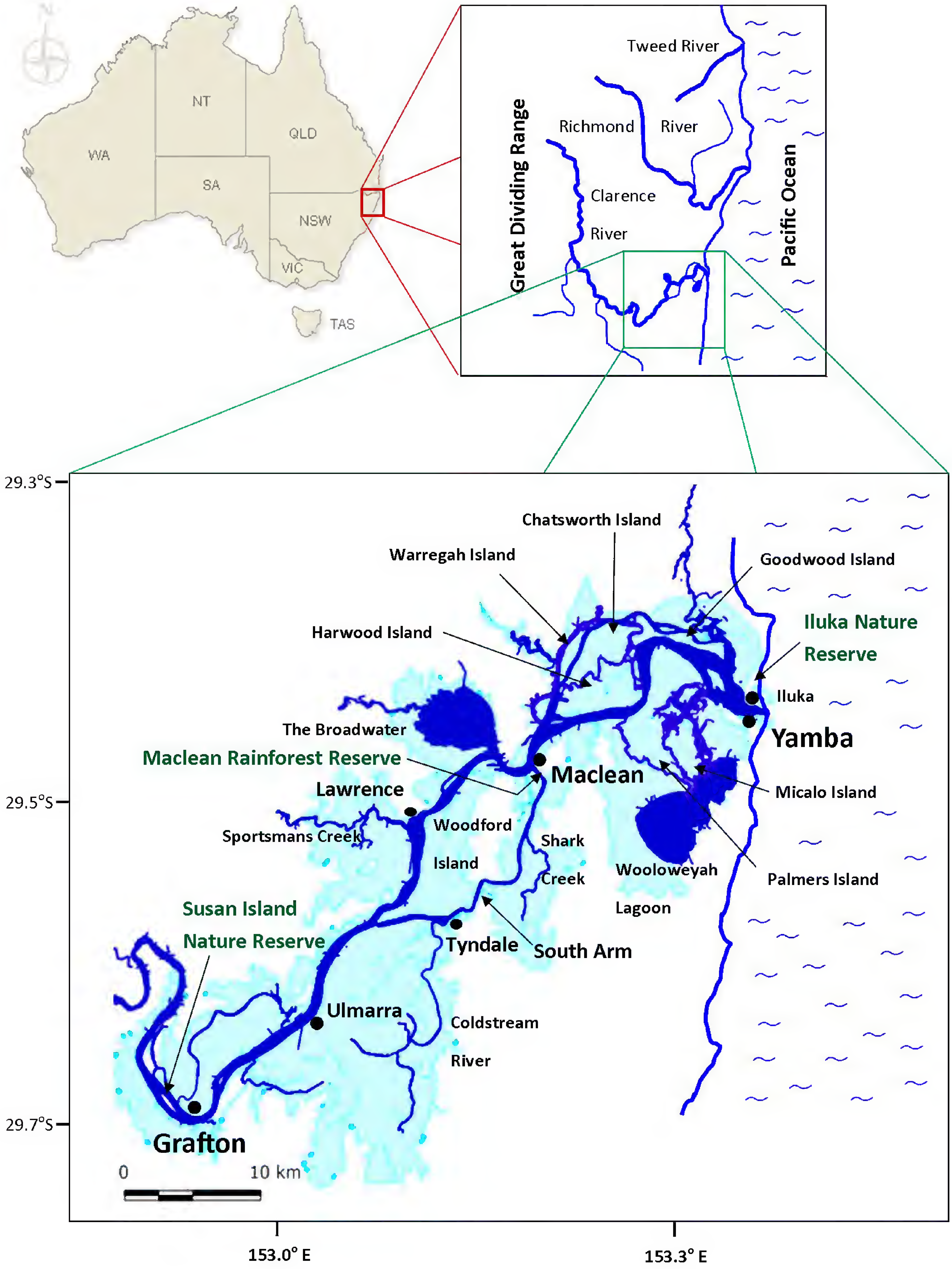

Figure 1. Map showing the location of the Clarence River floodplain (light blue), streams, islands, towns and remnant rainforest reserves.

the logs (McFarlane 1924). In this way the rainforest was rapidly cleared from the banks of the Clarence.

Charles Moore, Director of the Sydney Botanical Gardens visited the area in 1861 and found that:

> *Even the banks of the Clarence, which some six or eight years ago presented on both sides one continuous mass of this description of forest, varying in breadth from one hundred yards to almost half-a-mile has been already cleared for many miles – the fate which will soon overtake all the brush country available for cultivation, unless the government cause reserves to be made for the preservation of at least some portion of a class of trees which are both interesting and beautiful, even if not otherwise valuable* (Moore 1861a).

By 1868 a reporter of the *Sydney Morning Herald* (16 December 1868 p. 5) found that:

> *The scrubs have wholly disappeared from the banks of the river and where once the vine clad trees rose up, wreathed with thick robes of foliage and tinted with bright flowers, there are now groups of farm buildings, lines of fencing, patches of garden, and green fields of waving corn.*

Another reporter (*Sydney Morning Herald,* 10 August 1871 p. 2) noted that near the mouth:

> *The thick brushes which once grew here have been cut down on most of the islands, and given place to cultivation.*

In his next article (*Sydney Morning Herald,* 14 August 1871 p. 2) he observes that:

> *The tourist may form some idea of the Clarence as it was when first discovered, in 1832, from the vegetation which still grows in rank luxuriance on some of the smaller islands – emerald gems in the glittering stream.*

implying that the rest of the brushes (or riparian rainforest) had been totally cleared by that time.

The purpose of this paper is to present the available information of the now largely destroyed riparian rainforest in a manner that could be of use for anyone wishing to reestablish parts of this rainforest. For example Clarence Valley Council has an Environmental Trust grant for Clarence Estuary Riparian and Wetland Restoration and is actively engaged in riparian weed control, native plant establishment and livestock exclusion fencing. Clarence Landcare has a project for the collection of local native seed species and growing the plants/trees for specific projects (Wilson 2014a). A workshop of the Clarence Floodplain and Estuary Partnership agreed that riparian rehabilitation to be a priority activity for the partners (Wilson 2014b). This paper may help these agencies in their riparian restoration work to seek out species that were originally there and not only those that are currently in the riparian zone.

The starting point for this investigation was the NSW Scientific Committee's (1999) Determination for lowland rainforest on floodplain as an Endangered Ecological Community for the New South Wales North Coast Bioregion. This determination uses Floyd's (1990) classification for rainforests. Floyd (1990, v.2 microfiche) recorded the species found in the three remaining rainforest remnants (Susan Island Nature Reserve, Maclean Rainforest Reserve and Iluka Nature Reserve, Figure 1) on or near the Clarence floodplain. Historical surveyors' corner tree data and species lists from botanists, who visited the area prior to the clearing of the riparian rainforest, was another source for rainforest species found on the floodplain. Rich (1996) suggested that littoral rainforest may extend further inland along estuarine river systems, and as suballiance No. 16 is the main suballiance at the Iluka littoral rainforest reserve, this suballiance was also included in all of the assessments.

The available habitat and historical information was used to determine if any of the eleven suballiances in the Determination (NSW Scientific Committee 1999) could be excluded from being present on the Clarence floodplain and enabled the generation of a conceptual model of the distribution of rainforest suballiances across the riparian levees on the Clarence floodplain.

Methods

Floyd (1990) used floristics or habitat characteristics to differentiate between rainforest suballiances with key characteristics based on soil type, location, altitude, rainfall etc. or a combination of habitat characteristics. Table 1 gives a simple scale created to subjectively assess the habitat of the Clarence floodplain to the habitat characteristics of the eleven suballiances (Floyd 1990) from the NSW Scientific Committees (1999) determination.

Table 1. Criteria used in assessing the habitat fit of Floyd's suballiances to the riparian rainforest on the Clarence floodplain.

Assessment criteria	Habitat fit category
Good fit – the habitat criterial for the suballiances aligns with the habitat of the floodplain – the main suballiances	1
Niches – the habitat criterial for the suballiances aligns with small areas on the floodplain – present throughout in small areas.	2
Edges – the habitat criteria for the suballiances does not align with the main area of the floodplain, but it does for adjoining areas – transitional	3
No fit – the habitat criterial for the suballiances do not fit with the floodplain or its adjoining areas.	4

Table 2. Numerical ratings applied to Floyd's (1990 v. 1 p. 23) abundance ratings

Abundance rating	**Basis for abundance rating**	**Numerical rating**
VC Very common	Top 1–6 most common species	10
C Common	More than 5 individuals	6
O Occasional	2 to about 5 individuals	3
R Rare	1 only seen	1

Table 3 Worked example of the process of plotting abundance Vs number of species. The value for *Ficus macrophylla* for Suballiance 1 is generated from it being present in two of four sites (data not shown) with abundance values of 3 (Occasional) and 6 (Common) to give a rounded down abundance value of 2.2 (sum of 9 divided by 4 = 2.25). This process was repeated for all the other suballiances of interest and also for another four species. The highlighted values are those that are plotted in Figure 2.

	Floyd's suballiances											
Species	1	2	3	4	5	6	16	23	24	25	26	33
Ficus macrophylla	2.2	5.0	8.4	1.0	0.7			2.6	1.4			0.2
Dendrocnide excelsa	3.8	5.0	6.0	1.3	1.8			3.0	2.0			1.6
Streblus brunonianus	1.0	5.0	5.6		1.5			9.2	3.3	8.7	0.2	0.2
Malotus philippensis	1.5	1.5	4.4	2.0	1.5			6.0	4.0	5.3		0.6
Cryptocarya obovata	1.0	6.0	4.0	1.7	2.8	1.0		0.6	2.3	4.0	0.8	1.4
Sum of average abundance values	9.5	22.5	28.4	6.0	8.3	1.0		21.4	13.0	18.0	1.0	4.0
Total abundance value	225	196	193	160	156	86	193	214	132	126	107	213
Percentage of example list of the total abundance	**4.2%**	**11.5%**	**14.7%**	**3.8%**	**5.3%**	**1.2%**	**0.0%**	**10.0%**	**9.8%**	**14.3%**	**0.9%**	**1.9%**
No. of species (max. 5)	5	5	5	4	5	1	0	5	5	3	2	5
Total No. of species	161	93	146	103	134	99	95	166	75	52	80	184
Percentage of example list of the total no. of species	**3.1%**	**5.4%**	**3.4%**	**3.9%**	**3.7%**	**1.0%**	**0.0%**	**3.0%**	**6.7%**	**5.8%**	**2.5%**	**2.7%**

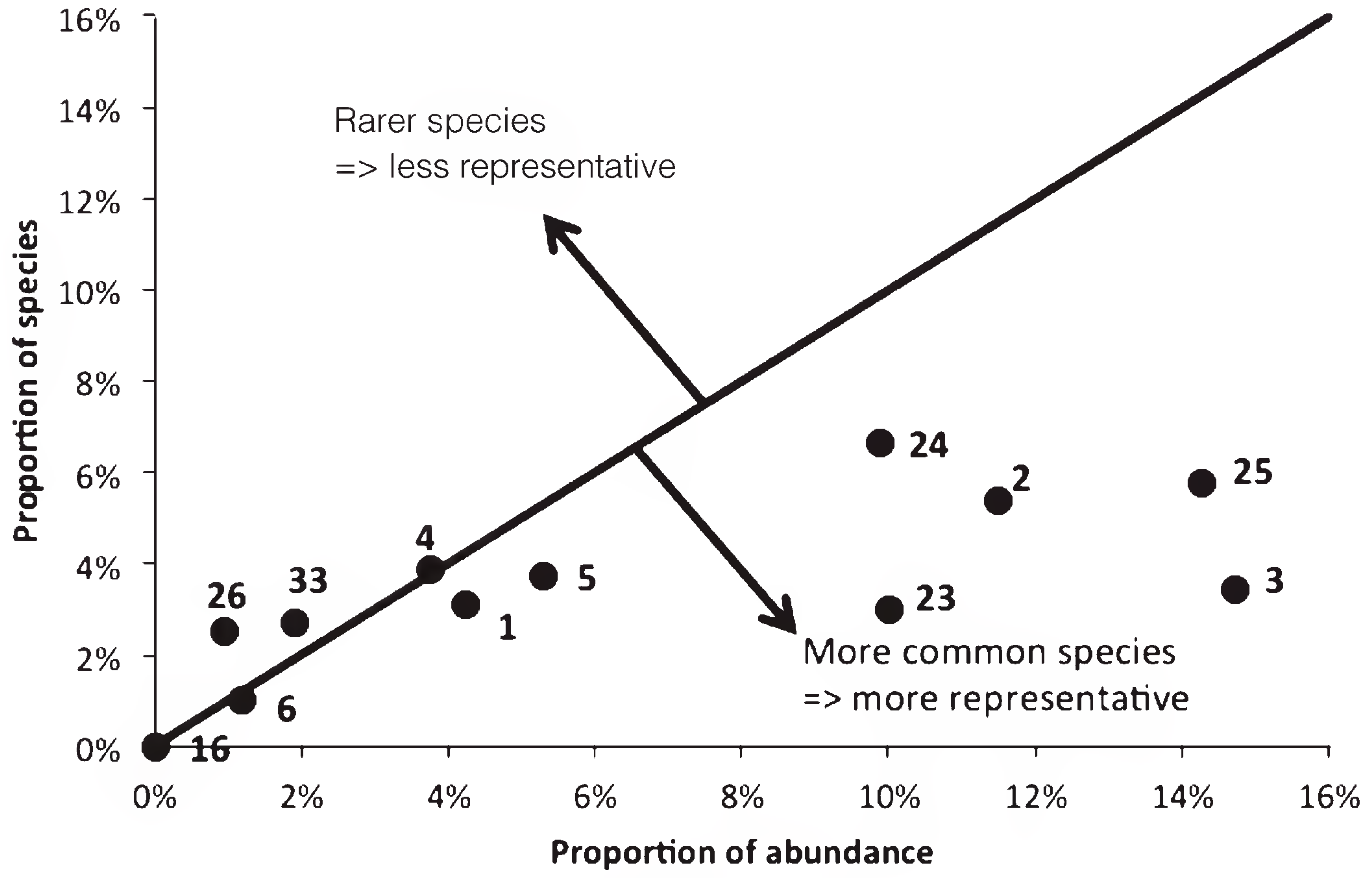

Figure 2 Worked example of plotting abundance Vs number of species. The graph has separated the suballiances into two groups. In the more representative group, only four of the seven suballiances where all five species were represented made it into this group. In suballiance 25, only 3 species were present, but due to them being very common, this suballiance has also made it into the more representative group. Using the proportion of numbers and abundance provides an extra dimension in trying to complete this historical jigsaw puzzle. Suballiances that are above the line will tend to be less representative, as the species that are present are less common. In contrast, those suballiances that are very abundant will tend to be placed below the dividing line, as their higher abundance values will push them to the right on the graph.

A species list was created from the original surveyors' corner tree data and species lists from botanists who visited the region prior to the clearing of the rainforest and will be referred to as the historical species list (Appendix 1).

The historical species list was compared to the species list in each of Floyd's (1990) suballiances to extract the number of species represented, and to generate an abundance rating. Floyd (1990) has provided a species list for each of his suballiances with an associated abundance rating from 2–5 representative sites. This abundance rating was converted to numerical values to reflect the relative weighting of the original rating (Table 2). It is a simple progressive scale with the interval between groups increasing by one and it aims to provide weight to the important species without completely ignoring the others. A linear scale (1, 2, 3, 4) was used initially but it was considered that it did not put enough emphasis on the very common species and too much emphasis on rare species.

The abundance values for each species were averaged to give an average abundance for that species in that suballiance. The average abundance values were then summed for the historical species that were present in each of the suballiances. The proportion of the sum of the abundance values for the historical species to the total of the abundance value for each suballiance was plotted against the proportion of the number of species from the historical list to the total number of species in the suballiance. This process is explained in a simplified example (Table 3, Figure 2).

Results

Two botanists' visited the region prior to the complete loss of the riparian rainforest, Charles Moore and William Carron.

Charles Moore (1861a, b, 1867), Director of the Sydney Botanic Gardens, collected many rainforest specimens on his visit to the Clarence in 1861, with 28 named in two separate newspaper articles. It is also recorded that he published *A catalogue of Northern Timbers*, which he later revised several times (King 1974). The Botanic Gardens Library (part of the National Herbarium of New South Wales) was not able to locate a copy of this Catalogue, but had a copy of his catalogue of *Woods indigenous to the Northern district of the colony* from the *London International Exhibition, 1862*. This catalogue had 116 timber specimens from the Clarence and Richmond districts, with 75 of these from the Clarence, some without species names.

William Carron (1872a, b), a collector for the Sydney Botanic Gardens was sent to the Northern Rivers to seek out possible sites for timber reserves. Only one rainforest timber reserve, located 6–7 miles (10–11 km) north of Grafton, with 20 tree species was nominated.

A list of 77 species (the historical species list, Appendix 1) was compiled from botanists' data combined with the surveyors' corner tree data. Though the corner tree data was only recorded as common names, it was possible to suggest a scientific name with the aid of a list of 78 species from the adjacent Richmond River region

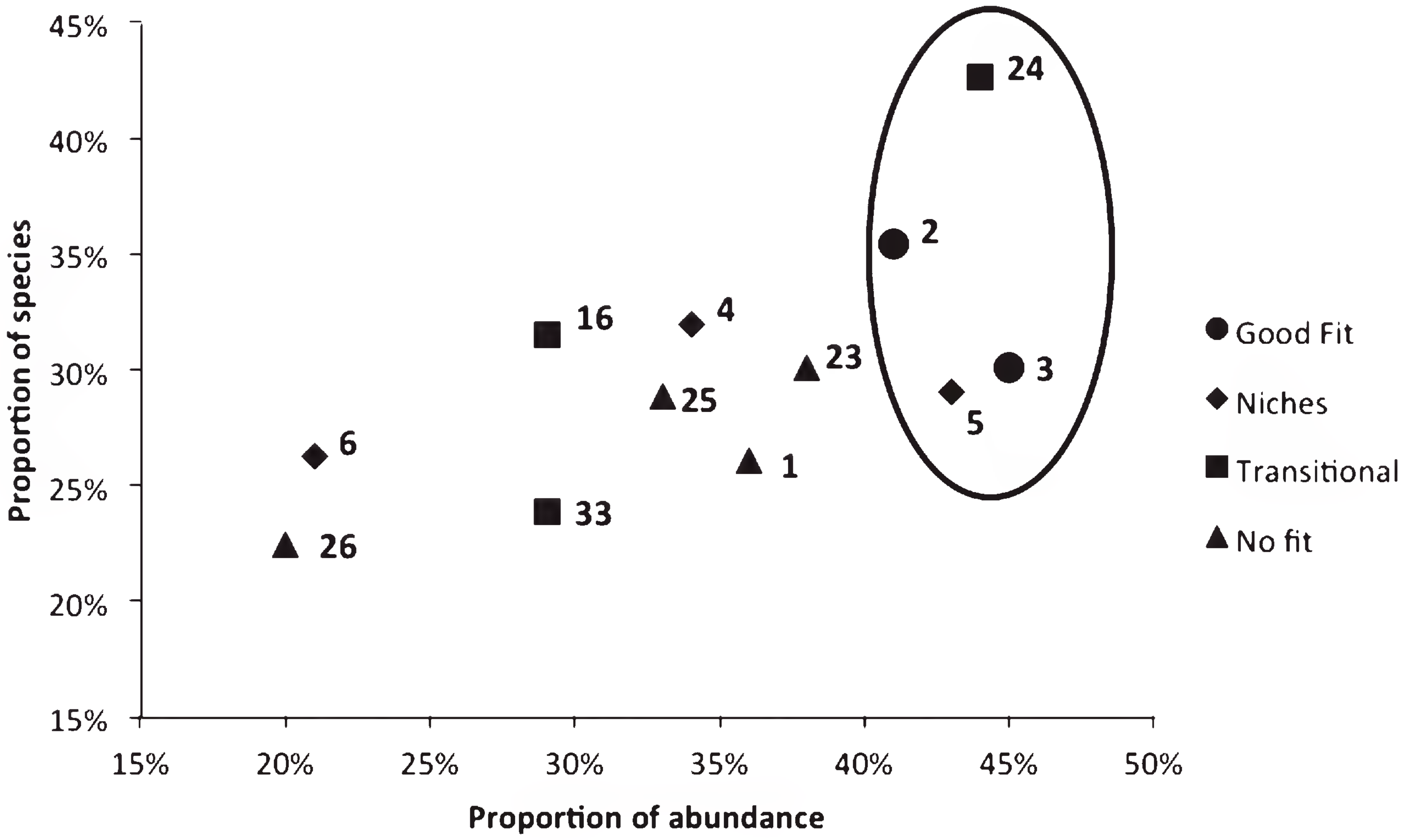

Figure 3. The proportion of species from the historical list in each of Floyd's (1990) suballiances (Table 4 for names) plotted against the proportion of the average abundance of that species in the suballiance with the subjective habitat rating displayed as various point shapes. The suballiances within the circle are those more likely to have been present on the Clarence floodplain.

Table 3. Possible explanations as to why these species were not represented in the 12 suballiances of interest.

No. of species	Reason
3	Only the genus was nominated
1	*Callerya megasperma* – A vine – only tree data has been captured in this project.
3	**Doubles** – two species names eventually converged to one species.
3	**These may be incorrectly named:**
	Acacia trinervata: Restricted to western Sydney and adjacent lower Blue Mountains (Flora of Australia v. 11B 2001 p. 45) and therefore may be incorrectly named.
	Epicarpurus orientalis: The common name of Elm and the description suggest the name *Aphananthe philippinensis* may be more correct.
	Owenia venosa: The common name of Tulipwood and the description suggest the name *Harpullia pendula* may be more correct.
4	**These species were not listed in the 12 suballiances of interest due to incorrect habitat:**
	Acacia binervata: In more or less abundance all along the coast; a handsome, small sized tree. Timber hard, and occasionally used for carpenters' tools. MALLA WAUNDIE. Clarence and Richmond brush forests (Moore 1861b).
	Denhamia pittosporoides: In dry rainforest and vine thicket on basaltic or basaltically enriched soil (Floyd 2008). A tree of moderate size; timber not used. Clarence brush forests (Moore 1861b).
	Erythrina vespertilio: Dry and semi-dry rainforests and also in adjoining open forest country (Floyd 2008). On open forest land bordering on the thick brush forests (Moore 1861b).
	Geijera salicifolia: In dry rainforest on steep dry stony slopes and sides of gorges. On skeletal soils derived from slates (Floyd 2008). Brush forests, generally in the Northern districts (Moore 1861b).
1	**This species may have been totally lost to NSW:**
	Cupaniopsis serrata: Not recorded with certainty in NSW. (Floyd 2008). A very ornamental tree of small size, plentiful in the brushes. Timber not used. GULWIN GULWIN. Richmond and Clarence (Moore 1861b).
2	**Unknowns** – The following species were unable to be located in the Australian Plant Name Index:
	Nephelium lanuginosum: Sapindaceae. A fine tree, attaining a height of 80 feet and 3 feet in diameter. Timber occasionally used for building purposes. UROOBIE. Clarence and Richmond brush forests, plentiful (Moore 1861b).
	Nephelium lucidum: Julip wood. This tree is very generally known wherever it grows, both on account of the beauty of its heart wood, and its excellence for firewood; for this latter purpose it is preferred about Grafton, where it is abundant, to almost any other. The tree grows to a large size, but it is seldom that the stem is solid, being generally decayed near the heart. The wood is exceedingly strong, and richly coloured with different shades, from black to yellow, will take a high polish, and in a good specimen is very beautiful. This has been occasionally employed in Sydney for cabinet work, but it does not appear to have received that attention that it deserves. (Moore 1861a, p.3)

(Clarence and Richmond Examiner and New England Advertiser, 1 April, 1873, Appendix 5). The likely current scientific and common names were determined using the Australian Plant Name Index (www.cpbr.gov.au/apni/) cross referenced with Floyd (2008). Of the 77 species in the complete list 60 were represented in the 12 suballiances that were deemed to be of interest (Appendix 2). An attempt has been made to ascertain why the other 17 species were not represented (Table 3).

The 12 suballiances were subjectively assessed for habitat fit (Table 4). The proportion of the sum of the average abundance values (Appendix 3) for each suballiance was plotted against the proportion of the number of species in each suballiance (Figure 3). In addition, the habitat fit rating of each suballiance was noted on the graph by different shape points. The resulting graph provided some insight on the fit of the 12 suballiances to the Clarence floodplain (Figure 3).

Discussion

The main criteria used to determine the possible distribution of Floyd's rainforest suballiances across the Clarence floodplain was a subjective assessment of the fit of the habitat characteristics of each suballiance to the habitat of the Clarence floodplain. To provide supporting evidence a methodology has been created that utilises a historical species list in a "what if" scenario. If the historical species list had been collected in a particular suballiance, then a particular proportion of the number of species and their abundance would have resulted. These values would vary for each suballiance along both axes, providing an extra dimension of the fit of each suballiance to the Clarence floodplain. There are many reasons why this methodology is not particularly robust, however, in much the same way that a palaeontologist will suggest how an animal may look, from a few bones, it is an attempt to use the available historical data to provide some insight into species distribution in rainforests that were cut down in the 1860s (Stubbs 1996, Rose 2012).

Table 4. Habitat descriptions of the suballiances nominated by the New South Wales Scientific Committee as being associated with the community lowland rainforest of New South Wales North Coast bioregion. In addition, the littoral suballiance No. 16 has been included. These have been ranked for habitat fit (Table 1) to the Clarence floodplain with qualifying remarks.

Suballiance	**Comments** (1st line – Suballiance name, 1st paragraph – comments from Floyd 1990 v.2; 2nd paragraph – qualifying remarks for the Clarence floodplain)	**Habitat fit categ.**
1	***Heritiera trifoliolatum*** Lowland krasnozem. North from Bellinger River. Less flood prone than No.3. Krasnozem soils are not present on the Clarence floodplain.	4
2	***Toona – Flindersia* spp.** Lowland alluvium. Well drained sites on the fertile alluvial flats, which were initially logged and now farmed. May suffer from seasonal moisture stress. Good fit for the Clarence floodplain as it has a low rainfall period during spring.	1
3	***Cryptocarya obovata – Dendrocnide excels – Ficus spp – Araucaria*** Floodplain alluvium. The major sub-alliance on the well-drained, fertile, basaltically-enriched alluvial lowland floodplains north from the Manning River, the majority now under agriculture. Good fit for the Clarence.	1
4	***Elaeocarpus grandis*** Streambank alluvium. Exists as a lowland riverine fringing community within a more extensive community eg No 5, 6 or 33. The stream bank location is due to the large fruit (up to 30mm diameter), which is dispersed by water and not by birds in New South Wales. This could have been a niche community along the banks of the Clarence.	2
5	***Castanospermum – Dysoxylum mollissimum*** Moist, alluvial flats and benches. A reliable soil moisture level appears to be a major requirement. Often derived from weathering of lowland plateaux. This suballiance can occur where hills merge with the floodplain without a backswamp in between e.g. at Maclean, Woodford Island, Ashby and Tyndale.	2
6	***Archontophoenix – Livistona*** Excess soil moisture. Also known as palm forests. Drainage is impeded and there is free surface water during the wet season. Soil type is not critical. No palm forests are indicated on the portion plans, only 'tall ferns'. However, it could be a transition community to the backswamps in some locations.	2
16	***Syzygium luehmannii – Acmena hemilampra*** Well developed littoral rainforest on deep sand. Rich (1996) has suggested that this suballiance can extend further up the rivers away from the true littoral zone and thus there could have been a transition from this to the main suballiances close to the mouth of the river.	3
23	***Ficus* spp *– Streblus – Dendrocnide – Cassine*** Central and South coasts on krasnozem at moderate low altitude. To the south of the Bellinger Valley. It occupies dry rocky slopes, ravines and headlands on fertile but often shallow soils. It does not occupy a streamside niche. Wrong location and soil type.	4
24	***Castanospermum – Grevillea robusta*** Gallery rainforest along streams on basaltic alluvium in minimal rainfall areas (950–1100mm). Mainly in the upper Clarence and Richmond valleys. A drier phase of the suballiance No. 5. The annual rainfall on the floodplain is too high for this suballiance to be a major component of the floodplain. However, it fits with the upper end of the floodplain around Grafton as a transition to the main suballiances.	3
25	***Streblus – Austromytus*** Streambank basaltic alluvium with high rainfall. Richmond River. Wrong location.	4
26	***Waterhousea floribunda/Tristaniopsis laurina*** Southern Extension of No. 24 on less fertile alluvium. Wrong location.	4
33	***Ceratopetalum/Schizomeria – Argyrodendron/Sloanea*** Warm temperate/subtropical rainforest on alluvium or enriched yellow earth. *Sloanea* above 650m altitude. A transition suballiance between the subtropical and warm temperate rainforests often in gullies. The floodplain environment on the Clarence of levees transitioning to backplains does not seem to fit this suballiance. Some small areas may be present as per the comments for No 5, in gullies that merge onto alluvial terraces.	3

Assessing habitat characteristics of the eleven rainforest suballiances nominated by the New South Wales Scientific Committee as possibly being present prior to European settlement on the Clarence floodplain, enabled four to be eliminated. Of the remaining suballiances it is suggested that three were present in niche environments, two plus a littoral rainforest suballiance occupied transitional environments and two were the main suballiances. The habitat ranking process for the suballiances was supported to some extent by the abundance and species number data generated from Floyd's (1990, v.2 microfiche) species lists when cross referenced with the historical species list (Appendix 1, Figure 3).

Suballiance No. 23 rated almost as high as the suballiances suggested for the Clarence floodplain (Figure 3), even though it is only present on the NSW Central and South Coasts. This could be due to either of two reasons: **Option 1**) Floyd (1990, v.1 p. 36) noted that in prior times that the region to the north of the Clarence was drier and seemed to be a major barrier to the north-south movement of some rainforest species. The concept of a species barrier was supported by Rich (1996) who grouped 33 littoral rainforest remnants from all of NSW into 3 groups using PATN analysis. The Iluka littoral rainforest near the mouth of the Clarence River was the northern most representative of the southern group, providing additional evidence of the Clarence as a boundary for some rainforest species. If the rainforest species on the floodplain followed the trend of the littoral rainforest species by having a stronger affinity with the southern rainforest groups, this could explain why the southern suballiance No. 23 rated so highly in Figure 3. **Option 2)** The second reason could be that those who contributed to the historical species list may have been more familiar with the rainforest species closer to home (Sydney), and so they were more familiar with the species from suballiance No. 23. The contrary argument to this option is the position of suballiance No. 23 in Figure 3, where it lies more to the right on the graph indicating that it is fairly well represented (Figure 3). If this option were true, it would be expected that the species would be less abundant and therefore placed further to the left in Figure 3.

Initial work with this concept using a smaller species list and plotting absolute numbers instead of proportions gave a poor rating for suballiance No. 25, which is described as being from the Richmond River (the next river valley to the north of the Clarence)(Rose 2012). This provided further evidence to support Option 1) above, however, with the revised methodology this is no longer as clear cut. Suballiance No. 25 is a dry rainforest type with a high rainfall, and as the lower Clarence floodplain has a relatively dry spring (Rose 2012, p. 24), it was expected that this suballiance would have a fit on the Clarence and perhaps it did. However, this is not a strong link and it can be argued that the data presented in Figure 3 could support the idea that at some time in the past the region directly to the north of the Clarence was a barrier for the north-south movement of rainforest species.

Floyd (1990, v.1 p 23) in setting up his classification of New South Wales Rainforests comments that:

> *It must be kept in mind at all times that the subformations, alliances and particularly the suballiances are merely nodes or fairly frequent clusters of species along a continuous graduation. Some areas will fall somewhere between two nodes or suballiances.*

Keeping these comments in mind a conceptual model of the possible distribution of suballiances throughout the Clarence floodplain is proposed with the boundaries in the diagram acting as transition zones (Figure 4). In this model suballiance No. 4 occupies sections directly on the

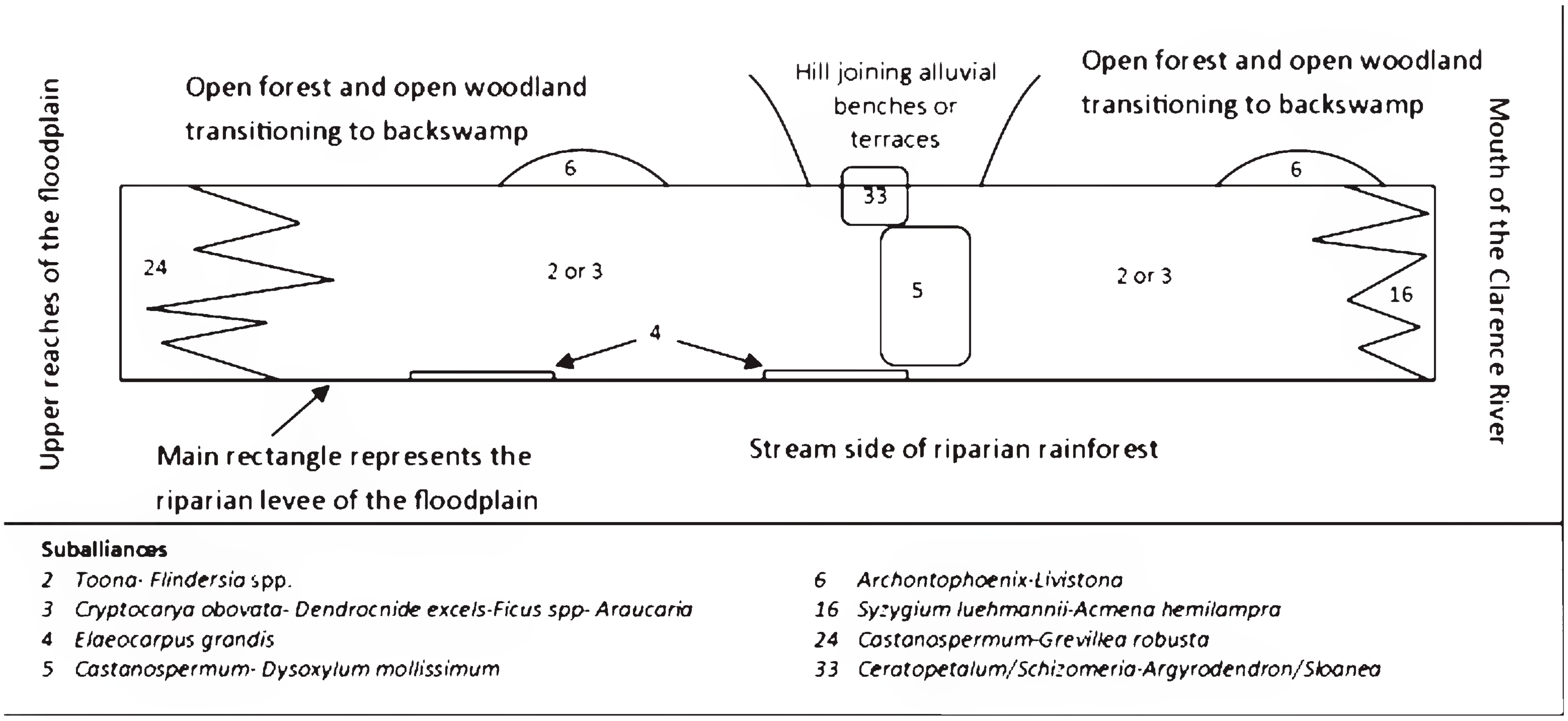
Upper reaches of the floodplain
Open forest and open woodland transitioning to backswamp
Hill joining alluvial benches or terraces
Open forest and open woodland transitioning to backswamp
Mouth of the Clarence River
6
33
6
24
2 or 3
5
2 or 3
16
4
Main rectangle represents the riparian levee of the floodplain
Stream side of riparian rainforest
Suballiances
2 Toona- Flindersia spp.
3 Cryptocarya obovata- Dendrocnide excels-Ficus spp- Araucaria
4 Elaeocarpus grandis
5 Castanospermum- Dysoxylum mollissimum
6 Archontophoenix-Livistona
16 Syzygium luehmannii-Acmena hemilampra
24 Castanospermum-Grevillea robusta
33 Ceratopetalum/Schizomeria-Argyrodendron/Sloanea

Figure 4. Proposed conceptual model of the occurrence and arrangement of the various rainforest suballiances on the Clarence floodplain.

riverbank, transitioning to the two major and one niche suballiance that occupy the bulk of the alluvial streamside levees. The two major suballiances are No. 2 and No. 3. Floyd indicates that suballiance No. 2 may suffer from seasonal moisture stress, which is a characteristic of the Clarence floodplain during spring. A climate and geomorphological (e.g. bank height, Rose 2012) gradient does exist along the Clarence floodplain and some species differentiation would be expected as a consequence. The corner trees from the portion plans provided some data on species distribution; however, only two rainforest species had more than four representatives, making any subregional suballiance delineation highly speculative.

Apart from Carron's Grafton brush species list (Appendix I), the only species location comments in the historical record refer to the Hoop pine, *Araucaria cunninghamii*, in the lower river:

> (i) Hodgkinson (1845 p. 97) notes that: *The brushes near the mouth of the Clarence are interspersed with the beautiful variety of pine I have already described…*
>
> (ii) Perry investigating a northern branch off the main river not far from the mouth (perhaps around Chatsworth Island via Middle Channel) found … *some nooks presenting pine brushes. The height of the pine trees, at the full growth, is about ninety feet, and they are as straight as an arrow.* (Lang 1847, p. 45)
>
> (iii) Pines were used as corner trees in four instances, all from Warregah Island. The only instance where pines were specifically referred to on portion plans was as a pine forest near the current day Maclean golf course (northern end of Woodford Island), which is upstream from where the above comments were made.

Floyd's (1990, v.2 microfiche) species lists indicate that *Araucaria cunninghamii* is present in suballiance No. 3 but not in suballiance No. 2, providing some support that at least on the lower floodplain that suballiance No. 3 may have been more dominant than suballiance No. 2.

Floyd commented that the rainforest on Susan Island, located at the upper reaches of the floodplain, contains four emergent species typical of dry rainforest. As a consequence, the conceptual model includes a zone of transition at the upper end of the floodplain from the two major suballiances No. 2 and No. 3 into the dry rainforest suballiance No. 24. This suballiance is present in the upper reaches of the Clarence River and plausibly could have transitioned into the floodplain. Suballiance No. 24 rates very highly in Figure 3 and sits on the midline between less and more representative. This indicates that a lot of the less abundant species from this suballiance were known to those, who contributed to the historical species list. Most of these people would have been based in Grafton during their visit to the region and it is plausible that their knowledge of the rainforest species closer to Grafton would have been better than those further away. However, as Suballiance 24 does not sit further to the right in Figure 3, it is fair to place it as a transitional suballiance on the Clarence floodplain.

At the mouth of the Clarence a zone of transition to the littoral rainforest suballiance No. 16 is included. Rich (1996) has suggested that littoral rainforest can be found inland as far as 3.1km and further inland along estuarine rivers (e.g. Stotts Island on the Tweed River is 15 km upstream and 8 km inland). The analysis of the historical data rates suballiance No. 16 on the midline between less and more representative, which is indicative of a transitional suballiance – the species are present to some extent, but as they are not fully suited, are not all that abundant.

The niche suballiance present in the main body of the riparian rainforest is suballiance No. 5, which is present on alluvial flats or benches that have been created by the weathering of an adjacent hill or plateau. A number of situations exist on the floodplain where the geomorphology is stream-bench-hill, without a backswamp in between e.g. near Maclean High School, where a remnant of this suballiance used to exist until destroyed by flying

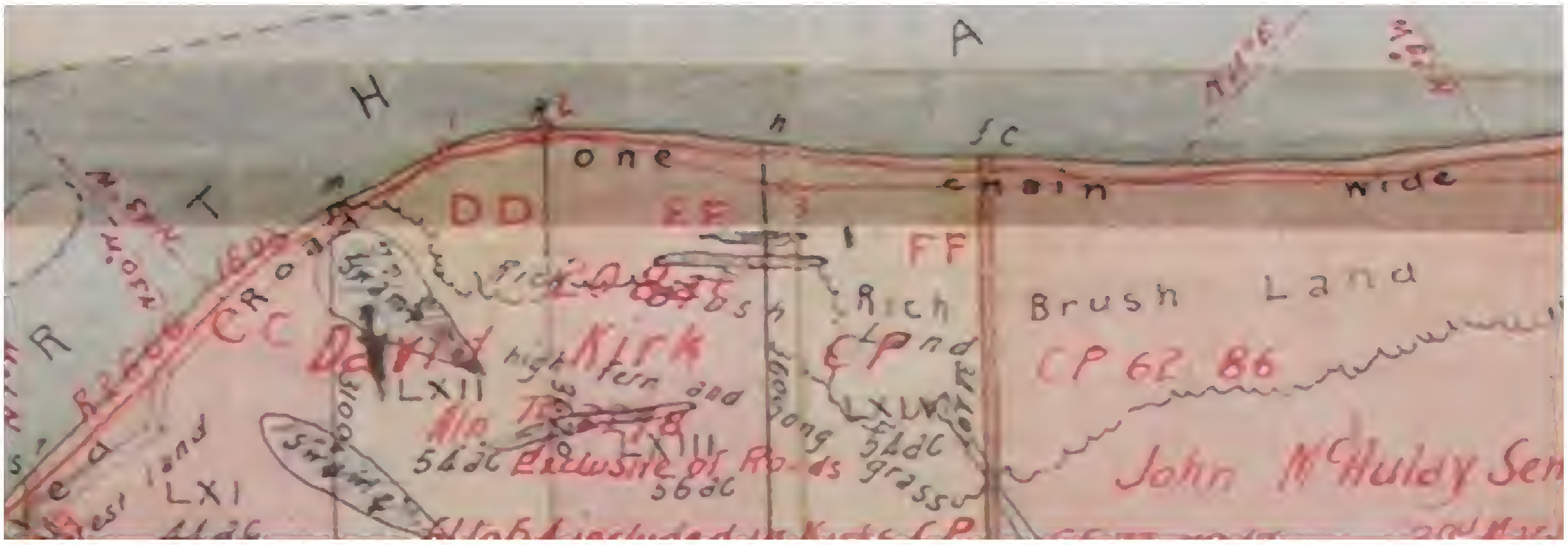

Figure 5 Portion plan of the northern part of Chatsworth Island showing a reference to 'high fern and long grass'. Surveyed 1862. (Department of Lands, Grafton, C62)

foxes (Silver 2010). It is possible that this suballiance transitioned into the warm rainforest suballiance No. 33 from the bench into gullies in the adjacent hill. It has been included as such in the conceptual model.

Floyd (1990 v.2 p. 23) notes that there are two examples of suballiance No. 6 in the lower Clarence region, with one on the floodplain. An early newspaper article about Susan Island records among other plants that Bangalow palms (*Archontophoenix cunninghamiana*) are present (Clarence and Richmond Examiner and New England Advertiser, 20 January, 1880, p. 3). As expected this suballiance rates poorly in the historical data analysis (Figure 3) as only a few species have high abundance ratings (Appendix 4). From a habitat point of view suballiance No. 6 fits as a transition suballiance from the main body of the riparian rainforest to the backswamps. As noted previously, both Hodgkinson and Perry commented on the abundance of pines on the lower river. Hoop pines (*Araucaria cunninghamii*) were observed at Stotts Island (Tweed River, northern New South Wales) within one of the largest examples of suballiance No. 6, where they are present on slightly higher areas in amongst the palm trees (Floyd, 1990, v. 2 p. 22). There were no references to palm forests on the 1860s portion plans. There were, however, many references to 'high fern' (e.g. Figure 5) in the areas where this suballiance may have been expected to be present but no documentation was found to confirm its identity (possibly Bracken *Pteridium esculentum*, Ed.).

As an aid to those using the suballiance conceptual model (Figure 4), the 45 most abundant species in Floyds (1990) species list from each suballiance as determined by the ranking system used in Table 1 is given in Appendix 4.

A total of 17 species from the historical list were not present in the 12 suballiances of interest. Most of these species were collected by Moore in 1861, at a time when there were still substantial areas of rainforest on the floodplain. A reason for their absence could be found for most of the species, however, two species were not able to be located in the Australian Plant Name Index and one (*Cupaniopsis serrata*) may have been totally lost to New South Wales. The presence of these species in the historical list indicate that the remaining rainforest remnants do not necessarily fully represent what was originally there. This is quite plausible, as the remnants are in locations that are not typical of the habitat of the majority of the original riparian rainforest. The conceptual model (Figure 4) cannot be classified as a complete solution, but based on the currently available evidence, as presented in this paper, it may be a fair representation of what may have been there.

Conclusion

We may never know the true species composition of the original riparian rainforest of the Clarence floodplain, but this paper has attempted to use the available information to generate a concept of what may have been there. Models do not always generate the correct answer. They do, however, provide a framework that promotes discussion and the basis for the construction of alternatives.

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The guidance of Alison Specht, Michael Whelan and Brett Stubbs was greatly appreciated. Thanks to Miguel Garcia for tracking down Moore's list of rainforest species from the northern districts.

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Appendix 1. Historical species list – Brush (rainforest) species from the Clarence floodplain as recorded in the mid-19th century

	Described by			Common names			Likely current names from the Australian Plant Name Index	
Scientific name (at time of description)	**Moore**	**Carron**	**Surveyors**	**Moore (1861)**	**Carron (1871)**	**Surveyors (Wilson: 1841–42, others: 1857–1870)**	**Scientific name**	**Common name**
Acacia cunninghamii	•			Bastard Myall			*Acacia trinervata*	Three-veined wattle
Acacia umbrosa	•			Malla waundie			*Acacia binervata*	Two-veined hickory
Achras australis	•			Native plum or iron wood			*Pouteria australis*	Black apple
Acmena spp	•			Hickory or lignum vitae			Myrtaceae	
Acronychia hillii	•						*Sarcomelicope simplicifolia* subsp. *simplicifolia*	Yellowwood
Ailantus spp.	•			Agundi-gundie			*Ailanthus triphysa*	White bean
Alphitonia excellea	•	•		Mountain ash	red ash		*Alphitonia excelsa*	Red ash
Araucaria cunninghamii	•	•	•	Pine	Morton Bay pine	Pine	*Araucaria cunninghamii*	Hoop pine
Atherosperma micranthum *Daphnandra micrantha*	•	•		Tdun-dambie	light yellow wood		*Daphnandra micrantha*	Manning River socketwood
Baloghia lucida	•			Nun nala			*Baloghia inophylla*	Brush bloodwood
Brachychiton luridum	•			sycamore			*Brachychiton discolor*	Brush kurrajong
Busbeckia arborea	•			Tree Caper			*Capparis arborea*	Brush caper berry
Cargillia pentamera	•	•		black myrtle	black-myrtle		*Diospyros pentamera*	Grey persimmon
Castanospermum australe	•	•	•	Moreton Bay Chestnut or bean tree	bean-tree	Bean	*Castanospermum australe*	Black bean
Cedreia toona	•	•	•	Cedar	red cedar	Cedar	*Toona ciliata*	Red cedar
Celtis opaca	•						*Celtis paniculata*	Native hackberry
Commersonia spp.	•			Brown Kurrajong			*Commersonia bartramia*	Brown kurrajong
Cryptocarya glaucescens	•			White sycamore			*Cryptocarya glaucescens*	Silver sycamore
Cryptocarya obovata	•							
Tetranthera ferruginea	•			ugaulbie			*Cryptocarya obovata*	Pepperberry
Cupania anacardioides	•						*Cupaniopsis anacardioides*	Tuckeroo
Cupania australis	•			Native tamarind			*Diploglottis australis*	Native tamarind
Diploglottis cunninghamii	•							

	Described by			**Common names**			**Likely current names from the Australian Plant Name Index**	
Scientific name (at time of description)	**Moore**	**Carron**	**Surveyors**	**Moore (1861)**	**Carron (1871)**	**Surveyors (Wilson: 1841–42, others: 1857–1870)**	**Scientific name**	**Common name**
Cupania pseud-orchis	•			Iccaaya			*Jagera pseudorhus*	Foambark Tree
Cupania semiglauca	•	•					*Guioa semiglauca*	Wild quince
Cupania serrata	•			Gulwin gulwin			*Cupaniopsis serrata*	Smooth tuckeroo
Cupania xylocarpa	•			wootarie			*Elattostachys xylocarpa*	White tamarind
Diospyros spp.	•						Diospyros spp	
Denhamia pittosporoides	•						*Denhamia pittosporoides*	Orange boxwood
Duboisia myoporoides	•		•	Corkwood		Cork	*Duboisia myoporoides*	Cork
Dysoxylon fraserianum	•	•	•		rosewood	Rosewood	*Dysoxylum fraserianum*	Rosewood, Rose mahogany
Dysoxylon muelleri	•			Pencil cedar or turnip wood			*Dysoxylum mollissimum*	Miva mahogany
Echinocarpus australis	•						*Sloanea australis*	Blush alder
Endiandra virens	•			Bat & Ball, Native pomegranate			*Endiandra virens*	White apple
Epicarpurus orientalis	•			Elm			*Epicarpurus orientalis*	
Erythrina vespertilionis	•						*Erythrina vespertilio*	Grey corkwood
Eugenia ventenatii	•			Large-leafed water gum			*Syzygium floribundum*	Weeping satinash
Euodia erythrococca	•						*Dinosperma erythrococcum*	Tingle-tongue
Ficus aspera	•			Small leafed fig			*Ficus obliqua*	Small leaved fig
Ficus macrophylla	•		•	Large leaved fig		Fig	*Ficus macrophylla*	Moreton Bay fig
Flindersia australis	•		•	Ash, beech		Ash	*Flindersia australis*	Crows ash
			•			Whitewood	*Flindersia schottiana*	
Geijera salicifolia	•			Balsam Capivi tree			*Geijera salicifolia*	Green satinheart
Geissois benthamii	•						*Geissois benthamii*	Brush mahogany
			•			Beech	*Gmelina leichhardtii*	White beech
Grevillea robusta	•	•			silky-oak		*Grevillea robusta*	Southern silky oak
Harpullia pendula	•	•	•		tulip-wood	Tulip	*Harpullia pendula*	Tulipwood
Hartighsia rufa	•			Woggi-amabbie			*Dysoxylum rufum*	Rusty mahogany
Hodgkinsonia ovatiflora	•			larribie			*Hodgkinsonia ovatiflora*	Golden ash
Jambosa australis	•			Cherry of the Clarence			*Syzygium australe*	Brush cherry
Lophostemon australis	•						*Lophostemon confertus*	Brush box
Mooria campylosperma.	•			Urra wymbie			*Citronella moori*	Soapy box
Morus brunoniana	•			lagaulbie			*Streblus brunonianus*	Whalebone tree
Myrtus acmenoides	•	•	•	White myrtle	hickory	Hickory	*Gossia acmenoides*	Ironwood
Myrtus melastom?e	•						*Rhodamnia rubescens*	Brush turpentine
Nephelium lanuginosum	•			uroobie				
Nephelium leiocarpum		•					*Alectryon subcinereus*	Wild quince, bird's eye
Nephelium lucidum	•			Julip wood				
Olea paniculata	•	•		marblewood	marble-wood		*Olea paniculata*	Native olive
Owenia venosa	•			Tulip wood			*Owenia venosa*	Tulipwood
Panax elegans	•			undambie			*Polyscias elegans*	Celery wood
Pseudalangium spp.	•			Walm babie			*Alangium villosum subsp. polyosmoides*	Black muskheart

	Described by			Common names			Likely current names from the Australian Plant Name Index	
Scientific name (at time of description)	**Moore**	**Carron**	**Surveyors**	**Moore (1861)**	**Carron (1871)**	**Surveyors (Wilson: 1841–42, others: 1857–1870)**	**Scientific name**	**Common name**
Rhus rhodanthema	•	•	•	light yellow wood	satin or yellow wood	Yellowwood	*Rhodosphaera rhodanthema*	Tulip satinwood
Rottlera discolor	•						*Mallotus discolor*	Yellow kamala
Rottlera tinctoria	•						*Mallotus philippensis*	Orange kamala
Schmidelia anodonta	•			gomphan			*Mischocarpus anodontus*	Pear fruited tamarind
Stenocarpus salignus	•			beefwood or silky oak			*Stenocarpus salignus*	Red silky oak
Stenocarpus sinuatue		•			beefwood or silky oak		*Stenocarpus sinuatus*	White silky oak
Synoum glandulosum	•			Rosewood			*Synoum glandulosum*	Scentless rosewood
Tabern?emontana spp.	•			Bitter bark				
Tarrietia argyrodendron	•			Iron wood or byong			*Heritiera trifoliolatum*	Brown tulip oak
Trochocarpa laurina		•			bush cherry		*Trochocarpa laurina*	
Urtica gigas	•		•	Large Nettle tree		Nettle	*Dendrocnide excelsa*	Giant stinging tree
Urtica photiniophylla	•			Small-leaved nettle			*Dendrocnide photinophylla*	Shining leaved stinging tree
Vitex spp	•			Beech-tree			*Premna lignum-vitae*	Yellow hollywood
Wistaria megasperma	•						*Callerya megasperma*	Native wistaria

Appendix 2. The 60 species of the total of 77 species from the historical list (Appendix 1) also present in Floyd's (1990) species list.

Family	Species	Name in 1990	Common name
Alangiaceae	*Alangium villosum*		Black muskheart
Anacardiaceae	*Rhodosphaera rhodanthema*		Deep yellowwood
Araliaceae	*Polyscias elegans*		Celery wood
Araucariaceae	*Araucaria cunninghamii*		Hoop pine
Cannabaceae	*Celtis paniculata*	Fa. Ulmaceae	Native hackberry
Capparaceae	*Capparis arborea*		Native pomegranate
Cardiopteridaceae	*Citronella moorei*	Fa. Icacinaceae	Soapy Box
Cunoniaceae	*Geissois benthamii*		Red carabeen
Ebenaceae	*Diospyros pentamera*		Grey persimon
Elaeocarpaceae	*Sloanea australis*		Mainden's blush
Epacridaceae	*Trochocarpa laurina*		Tree heath
Euphorbiaceae	*Baloghia inophylla*		Brush bloodwood
	Mallotus discolor		Yellow kamalla
	Mallotus philippensis		Orange kamalla
Fabaceae	*Castanospermum australe*		Black bean
Lauraceae	*Cryptocarya glaucescens*		Jackwood
	Cryptocarya obovata		Pepperberry
	Endiandra virens		White apple
Meliaceae	*Dyoxylum fraserianum*		Rosewood
	Dysoxylum mollissimum	*Dysoxylum muelleri*	Red bean
	Dyoxylum rufum		Hairy Rosewood
	Synoum glandulosum		Scentless rosewood
	Toona ciliata	*Toona australis*	Red cedar
Monimiaceae	*Daphnandra micrantha*	Fa. Atherospermataceae	Socketwood
Moraceae	*Ficus macrophylla*		Moreton Bay fig
	Ficus obliqua		Small leaved fig
	Streblus brunonianus		Whalebone tree

Family	Species	Name in 1990	Common name
Myrtaceae	*Gossia acmenoides*	*Austromyrtus acmenoides*	Scrub ironwood
	Lophostemon confertus		Brush box
	Rhodamnia rubescens		Scub turpentine
	Syzygium australe		Brush cherry
	Syzygium floribundum	*Waterhousea floribunda*	Weeping myrtle
Oleraceae	*Olea paniculata*		Native olive
Proteaceae	*Grevillea robusta*		Silky oak
	Stenocarpus salignus		Scrub beefwood
	Stenocarpus sinuatus		Wheel of fire tree
Rhamnaceae	*Alphitonia excelsa*		Red ash
Rubiaceae	*Hodgkinsonia ovatiflora*		Golden ash
Rutaceae	*Dinosperma erythrococcum*	*Melicope erthrococca*	Tingletongue
	Flindersia australis		Teak
	Flindersia schottiana		Bumpy ash
	Sarcomelicope simplicifolia		Yellow acronychia
Sapindaceae	*Alectryon subcinereus*		Wild quince
	Cupaniopsis anacardioides		Tuckeroo
	Diploglottis australis		Tamarind
	Elattostachys xylocarpa		Short-leaf beetroot
	Guioa semiglauca		Guioa
	Harpullia pendula		Tulipwood
	Jagera pseudohus		Foambark
	Mischocarpus anodontus		Few-leaved brush apple
Sapotaceae	*Pouteria australis*	*Planchonella australis*	Black apple
Simaroubaceae	*Ailanthus triphysa*		White bean
Solenaceae	*Duboisia myoporoides*		Soft corkwood
Sterculiaceae	*Heritiera trifoliolatum*	*Argyrodendron trifoliolatum*	White booyong
	Brachychiton discolor		Lacebark tree
	Commersonia bartramia		Brown kurrajong
Urticaceae	*Dendrocnide excelsa*		Giant stinging tree
	Dendrocnide photinophylla		Shining-leaved stinging tree
Verbenaceae	*Gmelina leichhardtii*		white beech
	Premna lignum-vitae		Lignum-vitae

Appendix 3. The historical list of species (Appendix 2) with average abundance data using the rating in Table 2 applied to the abundance data taken from Floyd (1990).

	Floyd's suballiances											
Species	**1**	**2**	**3**	**4**	**5**	**6**	**16**	**23**	**24**	**25**	**26**	**33**
Ailanthus triphysa	1.5						0.8	0.2	0.3			0.2
Alangium villosum	1.5	3.5	2.8	1.3	1.5	0.2	1	0.2				1.2
Alectryon subcinereus	0.5	0.5	0.6	1				2.6	1.3		0.3	0.8
Alphitonia excelsa	1.8	2	2.6	0.3	1.8	0.2	0.8	2.6	0.3	3	4.8	2.4
Araucaria cunninghamii			1.4			0.6	1.5	0.6	0.3			
Argyrodendron trifoliolatum	9.0	1	2.4	0.3	2.3			0.6	2			1.2
Austromyrtus acmenoides		1.5	0.2					0.8		2.3		0.2
Baloghia inophylla	2.5	1.5	1.2		1	0.6	0.3	3.8	5.3		0.8	2.6
Brachychiton discolor		0.5	1.8					1.2	0.3			
Capparis arborea	1.5		2.6	1	1			3.8		4		
Castanospermum australe	1.0		2.6	1	10				8.7	3		1.2
Celtis paniculata	05	1.5	0.8	0.3	1		1.8	0.4	1			
Citronella moorei	1.3	0.5		2	0.8			1.2				1
Commersonia bartramia	1.0	1.5	0.8	0.3	0.3		1.5	2	0.3			0.6
Cryptocarya glaucescens		1.5		1.3	0.3	0.6	0.3	0.2			3	2.8
Cryptocarya obovata	1.0	6	4	1.7	2.8	1		0.6	2.3	4	0.8	1.4
Cupaniopsis anacardioides			0.2		0.3	0.2	7.3	3.2				
Daphnandra micrantha	2.5	3	1.8	3.3		0.6		1.4	3		1.5	2.4
Dendrocnide excelsa	3.8	5	6	1.3	1.8			3	2			1.6

	Floyd's suballiances											
Species	**1**	**2**	**3**	**4**	**5**	**6**	**16**	**23**	**24**	**25**	**26**	**33**
Dendrocnide photinophylla	2.8	2	2	1.3	2.3		4.5	0.6	1			0.6
Diospyros pentamera	3.3	3	2.4		1.8	0.6	3.5	3.8	1	1		3
Diploglottis australis	2.5	3	2	3	2.5		0.8	2.2	1.3	1.3	0.8	2.2
Duboisia myoporoides	1.5		0.2									0.8
Dyoxylum fraserianum	2.0	2	0.2	1	1.5		0.8	2.4	2		0.8	1.6
Dyoxylum muelleri	2.5	0.5	1.2	3.3	5	0.8	1	0.6				0.6
Dyoxylum rufum	0.3	4.5	2.2	0.3	0.3		0.3	0.2	1			1.2
Elattostachys xylocarpa								0.6	0.3			
Endiandra virens	0.8											0.2
Ficus macrophylla	2.3	5	8.4	1	0.8			2.6	1.3			0.2
Ficus obliqua	2	1.5	3	0.3		0.2	1.8	0.8				
Flindersia australis	0.8		0.4		0.8			0.6				0.2
Flindersia schottiana			0.8	0.3	2.3		4.8	0.6				0.8
Geissois benthamii	3.8			2	3.3							5.2
Gmelina leichhardtii	0.8		0.2	1.3	0.3	0.2	1	0.6	0.3		0.3	1.6
Grevillea robusta		3	1.4						4.7	1.7	2.5	
Guioa semiglauca	2.5	0.5	2	1.3	1.5	0.6	4.5	4.4	1.3	2	2.3	2.4
Harpullia pendula	0.3	3.5	2.8		0.3	0.2	0.8					
Hodgkinsonia ovatiflora	0.5	0.5	0.8	1	0.8	1.2	4.3	0.4	0.3	1.3		0.2
Jagera pseudohus	1.8	3	3	0.3	2.3	0.6	1.3	1.4		2	1	0.8
Lophostemon confertus	4.5	1.5		2.3	1.8	0.6	3	1.2	0.3			3
Malotus discolor	2.5	1.5	0.6		1.5		1.5	0.6				0.2
Malotus philippensis	1.5	1.5	4.4	2	1.5			6	4	5.3		0.6
Melicope erythrococca								0.6				
Mischocarpus anodontus						0.2						
Olea paniculata	0.3		0.4			0.6	1	3.8	0.7			
Planchonella australis	1.8	0.5	2.4	1	1.3		1	2		0.7	1	1.6
Polyscias elegans	2.0	3	1.4	1	1.8	0.6	2	1.6	0.3			1.4
Premna lignum-vitae									1			
Rhodamnia rubescens	0.5	3			1	0.6		1.2				2.4
Rhodosphaera rhodanthema									1			
Sarcomelicope simplicifolia	0.8		0.4		1.8		1.5	2				0.4
Sloanea australis	5.8		2	7.7	3.3	2.6		0.6			0.3	3.2
Stenocarpus salignus								0.4				1.6
Stenocarpus sinuatus	0.8		0.6	1	0.8	0.2		0.6				0.2
Streblus brunonianus	1.0	5	5.6		1.5			9.2	3.3	8.7	0.3	0.2
Synoum glandulosum				2	0.8	1.8	0.3	0.6			0.8	3
Syzygium australe	1.5		1	2	0.3		1.8	0.8	4	1.3		0.8
Toona australis	0.3	5	1.4	5.3	2.3	0.2		1	2.3		0.8	0.6
Trochocarpa laurina						2.6	2.3	0.6				2.8
Waterhousea floribunda			1.8					0.6				
Sum of average abundance values	**82**	**83**	**87**	**56**	**69**	**18**	**58**	**84**	**59**	**42**	**22**	**63**
Total abundance value	**225**	**196**	**193**	**160**	**156**	**86**	**193**	**214**	**132**	**126**	**107**	**213**
Percentage of historial list of the total abundance	**37%**	**42%**	**45%**	**35%**	**44%**	**21%**	**30%**	**39%**	**45%**	**33%**	**20%**	**30%**
No. of species (max. 60)	**44**	**35**	**45**	**34**	**41**	**26**	**31**	**52**	**33**	**15**	**18**	**45**
Total No. of species	**161**	**93**	**146**	**103**	**134**	**99**	**95**	**166**	**75**	**52**	**80**	**184**
Percentage of historial list of the total no. of species	**27%**	**38%**	**31%**	**33%**	**31%**	**26%**	**33%**	**31%**	**44%**	**29%**	**23%**	**24%**

Appendix 4. Rainforest trees by suballiance that have been sorted by abundance.

These lists have been created from Floyd's species list (Floyd 1990, v. 2 microfiche) and have been sorted so that the top 45 most abundant species from the represented sites are listed. These could be the species to be used to start any rainforest recreation activities. This assumes that the more abundant species are the more successful in the ecological niche for that particular suballiance and therefore have the greatest chance of becoming established. These lists would be used in conjunction with the model of the location of the suballiances on the floodplain as an aid in species selection for any given site on the floodplain.

The lists show the species name using the 1990 names used in Floyd (1990). The abundance rating is shown for each of the listed sites and the average rating across all sites. In addition, the highest abundance rating for all sites is shown.

Table 2 (from main document) Numerical rating values applied to Floyd's (1990 v. 1 p. 23) abundance ratings.

Abundance rating		Basis for abundance rating	Numerical rating
VC	Very common	Top 1–6 most common species	10
C	Common	More than 5 individuals	6
O	Occasional	2 to about 5 individuals	3
R	Rare	1 only seen	1

Suballiance No. 2 *Toona – Flindersia* spp.

Site	Location
1	Stotts Is. N.R.
2	Hortons Ck., Leasehold

Family	Genus	Species	Common	Site		Av. abund. ratings	Max of abund. ratings
				1	2		
Sapindaceae	*Elattostachys*	*nervosa*	Beetroot	3	10	6.5	10
Lauraceae	*Cryptocarya*	*obovata*	Pepperberry	6	6	6	6
Rutaceae	*Flindersia*	*schottina*	Bumpy ash	6	6	6	6
Ulmaceae	*Aphananthe*	*philippinensis*	Native elm	10		5	10
Moraceae	*Ficus*	*macrophylla*	Moreton bay fig	10		5	10
Moraceae	*Streblus*	*brunonianus*	Whalebone tree	10		5	10
Urticaceae	*Dendrocnide*	*excelsa*	Giant stinging tree		10	5	10
Meliaceae	*Melia*	*azedarach* var. *australasica*	White cedar		10	5	10
Meliaceae	*Toona*	*australis*	Red cedar		10	5	10
Sterculiaceae	*Argyrodendron*	*actinophyllum*	Black booyong	10		5	10
Moraceae	*Ficus*	*coronata*	Creek sandpaper fig	6	3	4.5	6
Meliaceae	*Dyoxylum*	*rufum*	Hairy Rosewood	6	3	4.5	6
Sapindaceae	*Harpullia*	*pendula*	Tulipwood	6	1	3.5	6
Alangiaceae	*Alangium*	*villosum*	Black muskheart	1	6	3.5	6
Podocacarpaceae	*Podocarpus*	*elatus*	Brown pine	6		3	6
Arecaceae	*Archontophoenix*	*cunninghamiana*	Bangalow palm	3	3	3	3
Proteaceae	*Grevillea*	*robusta*	Silky oak		6	3	6
Atherospermataceae	*Daphnandra*	*micrantha*	Socketwood		6	3	6
Lauraceae	*Endiandra*	*muelleri*	Green-leaved rose walnut		6	3	6
Lauraceae	*Neolitsea*	*dealbata*	White bolly gum		6	3	6
Euphorbiaceae	*Cleistanthus*	*cunnunghamii*	Cleistanthus	6		3	6
Euphorbiaceae	*Croton*	*verreauxii*	Green native cascarilla	3	3	3	3
Euphorbiaceae	*Drypetes*	*australasica*	Yellow tulip	6		3	6
Celastraceae	*Denhamia*	*celastroides*	Orange boxwood		6	3	6
Sapindaceae	*Diploglottis*	*australis*	Tamarind	3	3	3	3
Sapindaceae	*Jagera*	*pseudohus*	Foambark	3	3	3	3
Elaeocarpaceae	*Elaeocarpus*	*grandis*	Blue fig	6		3	6
Elaeocarpaceae	*Elaeocarpus*	*obovatus*	Blueberry ash	6		3	6
Myrtaceae	*Austromyrtus*	*bidwillii*	Python tree	3	3	3	3
Myrtaceae	*Rhodamnia*	*rubescens*	Scub turpentine		6	3	6
Araliaceae	*Polyscias*	*legans*	Celery wood	3	3	3	3

Sapotaceae	*Planchonella*	*laurifolia*	Blush coondoo	6		3	6
Ebenaceae	*Diospyros*	*pentamera*	Grey persimon	3	3	3	3
Urticaceae	*Dendrocnide*	*photinophylla*	Shining-leaved stinging tree	1	3	2	3
Rutaceae	*Acronychia*	*oblongifolia*	Common acronychia	1	3	2	3
Meliaceae	*Dyoxylum*	*fraserianum*	Rosewood	1	3	2	3
Rhamnaceae	*Alphitonia*	*excelsa*	Red ash	3	1	2	3
Ulmaceae	*Celtis*	*paniculata*	Native hackberry	3		1.5	3
Moraceae	*Ficus*	*fraseri*	Sandpaper fig	3		1.5	3
Moraceae	*Ficus*	*obliqua*	Small-leaved fig	3		1.5	3
Moraceae	*Ficus*	*virens* var. *sublanceolata*	White fig	3		1.5	3
Moraceae	*Ficus*	*watkinsiana*	Strangler fig		3	1.5	3
Lauraceae	*Beilschmiedia*	*obtusifolia*	Hard bolly gum	3		1.5	3

Suballiance No. 3 *Cryptocarya obovata – Dendrocnide excels – Ficus spp – Araucaria*

Site	Location
1	Stotts Is. N.R.
2	Boat Harbour N.R.
3	Susan Island. N.R.
4	Bellingen Is. Rec. Res.
5	Wingham Brush Rec. & Flora Res.

						Site				
Family	**Genus**	**Species**	**Common**	**1**	**2**	**3**	**4**	**5**	**Av. abund. ratings**	**Max of abund. ratings**
Moraceae	*Ficus*	*macrophylla*	Moreton bay fig	10	6	10	6	10	8.4	10
Ulmaceae	*Aphananthe*	*philippinensis*	Native elm	10	10	6		10	7.2	10
Urticaceae	*Dendrocnide*	*excelsa*	Giant stinging tree			10	10	10	6	10
Moraceae	*Streblus*	*brunonianus*	Whalebone tree	6	6	10		6	5.6	10
Meliaceae	*Melia*	*azedarach* var. *australasica*	White cedar		3	3	6	10	4.4	10
Euphorbiaceae	*Malotus*	*philippensis*	Orange kamalla	3	10	6		3	4.4	10
Moraceae	*Ficus*	*coronata*	Creek sandpaper fig	1	3	6	10	1	4.2	10
Lauraceae	*Cryptocarya*	*obovata*	Pepperberry	3	10	1	3	3	4	10
Lauraceae	*Endiandra*	*pubens*	White bark walnut		10		6		3.2	10
Moraceae	*Ficus*	*obliqua*	Small-leaved fig	3	6		6		3	6
Sapindaceae	*Jagera*	*pseudohus*	Foambark		6	3	6		3	6
Sapindaceae	*Harpullia*	*pendula*	Tulipwood	3	1	10			2.8	10
Alangiaceae	*Alangium*	*villosum*	Black muskheart		1		3	10	2.8	10
Capparaceae	*Capparis*	*arborea*	Native pomegranate		6	1		6	2.6	6
Fabaceae	*Castanospermum*	*australe*	Black bean		6	3	1	3	2.6	6
Rutaceae	*Euodia*	*micrococca*	White euodia		6		6	1	2.6	6
Rhamnaceae	*Alphitonia*	*excelsa*	Red ash	3	6	3		1	2.6	6
Elaeocarpaceae	*Elaeocarpus*	*obovatus*	Blueberry ash	6	3	3		1	2.6	6
Myrtaceae	*Eucalyptus*	*tereticornis*	Forest red gum		3	10			2.6	10
Myrtaceae	*Syzygium*	*francisii*	Giant water-gum	6	6		1		2.6	6
Sterculiaceae	*Argyrodendron*	*trifoliolatum*	White booyong		6		6		2.4	6
Sapotaceae	*Planchonella*	*australis*	Black apple		6			6	2.4	6
Ebenaceae	*Diospyros*	*pentamera*	Grey persimon	3		3	3	3	2.4	3
Lauraceae	*Cinnamomum*	*oliveri*	Oliver's sasafrass		10		1		2.2	10
Meliaceae	*Dyoxylum*	*rufum*	Hairy Rosewood		3	1	1	6	2.2	6
Arecaceae	*Archontophoenix*	*cunninghamiana*	Bangalow palm	10					2	10
Moraceae	*Ficus*	*watkinsiana*	Strangler fig		3	1	6		2	6
Urticaceae	*Dendrocnide*	*photinophylla*	Shining-leaved stinging tree	1	6		3		2	6
Lauraceae	*Neolitsea*	*dealbata*	White bolly gum		3	1	3	3	2	3
Mimosaceae	*Pararchidendron*	*pruinosum*	Snow-wood		1	3	3	3	2	3
Sapindaceae	*Diploglottis*	*australis*	Tamarind		3		6	1	2	6
Sapindaceae	*Guioa*	*semiglauca*	Guioa	1	3		3	3	2	3
Elaeocarpaceae	*Sloanea*	*australis*	Mainden's blush				10		2	10
Atherospermataceae	*Daphnandra*	*micrantha*	Socketwood		3			6	1.8	6

Lauraceae	*Endiandra*	*muelleri*	Green-leaved rose walnut		6	3			1.8	6
Lauraceae	*Litsea*	*australis*	Brown bolly gum		6	3			1.8	6
Euphorbiaceae	*Drypetes*	*australasica*	Yellow tulip	6	3				1.8	6
Sapindaceae	*Elattostachys*	*nervosa*	Beetroot		3		3	3	1.8	3
Sterculiaceae	*Brachychiton*	*discolor*	Lacebark tree		3	6			1.8	6
Myrtaceae	*Waterhousea*	*floribunda*	Weeping myrtle				6	3	1.8	6
Araucariaceae	*Araucaria*	*cunninghamii*	Hoop pine	3	3			1	1.4	3
Moraceae	*Ficus*	*fraseri*	Sandpaper fig	1	3	3			1.4	3
Proteaceae	*Grevillea*	*robusta*	Silky oak		3	1	3		1.4	3

Suballiance No. 4 *Elaeocarpus grandis*

Site	**Location**
1	Wanganui P.P.
2	Terania Ck., Nightcap N.P.
3	Middle Ck., Gibraltar Range N.P.

Family	**Genus**	**Species**	**Common**		**Site**		**Av. abund. ratings**	**Max of abund. ratings**
				1	**2**	**3**		
Arecaceae	*Archontophoenix*	*cunninghamiana*	Bangalow palm	10	10	10	10.0	10
Elaeocarpaceae	*Sloanea*	*australis*	Mainden's blush	10	10	3	7.7	10
Elaeocarpaceae	*Elaeocarpus*	*grandis*	Blue fig	3	6	10	6.3	10
Escelloniaceae	*Cuttsia*	*viburnea*	Elderberry	3	3	10	5.3	10
Meliaceae	*Toona*	*australis*	Red cedar	10		6	5.3	10
Moraceae	*Ficus*	*coronata*	Creek sandpaper fig	6	6	3	5.0	6
Atherospermataceae	*Daphnandra*	*micrantha*	Socketwood	6	3	1	3.3	6
Lauraceae	*Cryptocarya*	*rigida*	Rose maple			10	3.3	10
Meliaceae	*Dyoxylum*	*melleri*	Red bean	10			3.3	10
Myrtaceae	*Syzygium*	*crebrinerva*	Purple cherry	10			3.3	10
Lauraceae	*Endiandra*	*pubens*	White bark walnut	6	3		3.0	6
Cunoniaceae	*Caldcluvia*	*paniculosa*	Corkwood	3		6	3.0	6
Euphorbiaceae	*Glochidion*	*ferdinandi*	Cheese tree	6		3	3.0	6
Sapindaceae	*Castanospora*	*alphandii*	Brown tamarind	6	3		3.0	6
Sapindaceae	*Diploglottis*	*australis*	Tamarind	6		3	3.0	6
Myrtaceae	*Austromyrtus*	*lasioclada*	Velvet myrtle	6	3		3.0	6
Moraceae	*Ficus*	*watkinsiana*	Strangler fig	1		6	2.3	6
Lauraceae	*Neolitsea*	*dealbata*	White bolly gum	1		6	2.3	6
Icacinaceae	*Pennantia*	*cunninghamii*	Brown beech	3	1	3	2.3	3
Myrtaceae	*Lophostemon*	*confertus*	Brush box	1		6	2.3	6
Cunoniaceae	*Geissois*	*benthamii*	Red carabeen	6			2.0	6
Meliaceae	*Synoum*	*glandulosum*	Scentless rosewood			6	2.0	6
Euphorbiaceae	*Malotus*	*philippensis*	Orange kamalla	3		3	2.0	3
Icacinaceae	*Citronella*	*moorei*	Soapy box	3		3	2.0	3
Myrtaceae	*Acema*	*smithii* var. *minor*	Small leaved lilly pilly	6			2.0	6
Myrtaceae	*Syzygium*	*australe*	Brush cherry			6	2.0	6
Myrtaceae	*Syzygium*	*hodgkinsoniae*	Smooth-bark rose apple	6			2.0	6
Myrtaceae	*Tristaniosis*	*laurina*	Water gum	6			2.0	6
Lauraceae	*Cryptocarya*	*obovata*	Pepperberry	3	1	1	1.7	3
Urticaceae	*Dendrocnide*	*excelsa*	Giant stinging tree	1		3	1.3	3
Urticaceae	*Dendrocnide*	*photinophylla*	Shining-leaved stinging tree	1		3	1.3	3
Eupomatiaceae	*Eupomatia*	*laurina*	Bolwarra	1		3	1.3	3
Lauraceae	*Cryptocarya*	*glaucescens*	Jackwood	1		3	1.3	3
Lauraceae	*Endiandra*	*muelleri*	Green-leaved rose walnut	3		1	1.3	3
Pittosporaceae	*Hymenosporum*	*flavum*	Native frangipani	1		3	1.3	3
Pittosporaceae	*Pittosporum*	*undulatum*	Sweet pittosporum	3		1	1.3	3
Cunoniaceae	*Ceratopetalum*	*apetalum*	Coachwood	1		3	1.3	3
Cunoniaceae	*Schizomeria*	*ovata*	Crabapple	1		3	1.3	3
Mimosaceae	*Acacia*	*melanoxylon*	Blackwood	1		3	1.3	3

Meliaceae	*Melia*	*azedarach* var. *australasica*	White cedar	1		3	1.3	3
Anacardiaceae	*Euroschinus*	*falcata*	Chinaman's cedar	3		1	1.3	3
Sapindaceae	*Guioa*	*semiglauca*	Guioa	1		3	1.3	3
Myrtaceae	*Syzygium*	*olersum*	Blue cherry	1		3	1.3	3

Suballiance No. 5 *Castanospermum – Dysoxylum mollissimum*

Site	Location
1	Couchy Ck., Numinbah N.R.
2	Boomerang Falls F.R.
3	Davis Scrub N.R.
4	Maclean Flora & Fauna Reserve

				Site				Av.	Max of
Family	**Genus**	**Species**	**Common**	**1**	**2**	**3**	**4**	**abund. ratings**	**abund. ratings**
Fabaceae	*Castanospermum*	*australe*	Black bean	10	10	10	10	10.0	10
Meliaceae	*Dyoxylum*	*muelleri*	Red bean			10	10	5.0	10
Cunoniaceae	*Geissois*	*benthamii*	Red carabeen	3	10			3.3	10
Elaeocarpaceae	*Sloanea*	*australis*	Mainden's blush		10	3		3.3	10
Meliaceae	*Anthocarapa*	*nitidula*	Bog onion	3	6	3		3.0	6
Lauraceae	*Cryptocarya*	*obovata*	Pepperberry	1	3	1	6	2.8	6
Moraceae	*Ficus*	*watkinsiana*	Strangler fig	6	3		1	2.5	6
Mimosaceae	*Pararchidendron*	*pruinosum*	Snow-wood	3	1	3	3	2.5	3
Sapindaceae	*Diploglottis*	*australis*	Tamarind	1	3	3	3	2.5	3
Moraceae	*Ficus*	*fraseri*	Sandpaper fig			6	3	2.3	6
Urticaceae	*Dendrocnide*	*photinophylla*	Shining-leaved stinging tree	6			3	2.3	6
Lauraceae	*Endiandra*	*muelleri*	Green-leaved rose walnut		3	6		2.3	6
Lauraceae	*Endiandra*	*pubens*	White bark walnut	3		6		2.3	6
Rutaceae	*Flindersia*	*schottina*	Bumpy ash			6	3	2.3	6
Meliaceae	*Toona*	*australis*	Red cedar	3		3	3	2.3	3
Sapindaceae	*Arytera*	*distylis*	Two-leaved coogara	6		3		2.3	6
Sapindaceae	*Jagera*	*pseudohus*	Foambark	3		3	3	2.3	3
Elaeocarpaceae	*Sloanea*	*woollsii*	Yellow carabeen		6	3		2.3	6
Sterculiaceae	*Argyrodendron*	*trifoliolatum*	White booyong	3	3	3		2.3	3
Sterculiaceae	*Brachychiton*	*acerifolius*	Flame tree	6	1	1		2.0	6
Ulmaceae	*Aphananthe*	*philippinensis*	Native elm			1	6	1.8	6
Urticaceae	*Dendrocnide*	*excelsa*	Giant stinging tree	3		3	1	1.8	3
Rutaceae	*Sarcomelicope*	*simplicifolia*	Yellow acronychia		1	3	3	1.8	3
Meliaceae	*Melia*	*azedarach* var. *australasica*	White cedar	3		3	1	1.8	3
Sapindaceae	*Sarcopteryx*	*stipata*	Steelwood	6		1		1.8	6
Rhamnaceae	*Alphitonia*	*excelsa*	Red ash	3		3	1	1.8	3
Myrtaceae	*Lophostemon*	*confertus*	Brush box	6			1	1.8	6
Myrtaceae	*Syzygium*	*crebrinerva*	Purple cherry		1	6		1.8	6
Myrtaceae	*Syzygium*	*hodgkinsoniae*	Smooth-bark rose apple	6		1		1.8	6
Araliaceae	*Polyscias*	*legans*	Celery wood	3		3	1	1.8	3
Ebenaceae	*Diospyros*	*pentamera*	Grey persimmon	3	1	3		1.8	3
Moraceae	*Streblus*	*brunonianus*	Whalebone tree				6	1.5	6
Proteaceae	*Macadamia*	*tetraphylla*	Rough-shelled bush nut			3	3	1.5	3
Atherospermataceae	*Daphnandra*	*tenuipes*	Red-flowered socketwood	3	3			1.5	3
Lauraceae	*Neolitsea*	*australiensis*	Smooth-barked booly gum			6		1.5	6
Lauraceae	*Neolitsea*	*dealbata*	White bolly gum	3		3		1.5	3
Cunoniaceae	*Pseudoweinmannia*	*lachnocarpa*	Mararie	6				1.5	6
Rutaceae	*Euodia*	*micrococca*	White euodia			6		1.5	6
Rutaceae	*Melicope*	*octandra*	Doughwood			6		1.5	6
Meliaceae	*Dyoxylum*	*fraserianum*	Rosewood	3		3		1.5	3
Euphorbiaceae	*Actephila*	*lindleyi*	Actephila			6		1.5	6
Euphorbiaceae	*Malotus*	*discolor*	Yellow kamalla			6		1.5	6
Euphorbiaceae	*Malotus*	*philippensis*	Orange kamalla			3	3	1.5	3

Suballiance No. 6 *Archontophoenix – Livistona*

Site	**Location**
1	Stotts Is. N.R.
2	Round Mtn. Lease
3	Terania Ck., Nightcap N.P.
4	Clarence Peak, freehold
5	Yahou Is. N.R.

Family	**Genus**	**Species**	**Common**	**Site**					**Av. abund. ratings**	**Max of abund. ratings**
				1	**2**	**3**	**4**	**5**		
Arecaceae	*Archontophoenix*	*cunninghamiana*	Bangalow palm	3	10	10	10		6.6	10
Arecaceae	*Livistona*	*australis*	Cabbage tree palm	10	3		10	10	6.6	10
Elaeocarpaceae	*Sloanea*	*australis*	Mainden's blush		3	10			2.6	10
Epacridaceae	*Trochocarpa*	*laurina*	Tree heath		3		10		2.6	10
Moraceae	*Ficus*	*coronata*	Creek sandpaper fig		6	6			2.4	6
Lauraceae	*Endiandra*	*discolor*	Rose walnut		6		6		2.4	6
Elaeocarpaceae	*Elaeocarpus*	*grandis*	Blue fig		6	6			2.4	6
Sapotaceae	*Planchonella*	*laurifolia*	Blush coondoo		10				2	10
Meliaceae	*Synoum*	*glandulosum*	Scentless rosewood		3		6		1.8	6
Euphorbiaceae	*Glochidion*	*ferdinandi*	Cheese tree				3	6	1.8	6
Myrtaceae	*Melaleuca*	*quinquenervia*	Broad-leaved paper-bark	3				6	1.8	6
Oleraceae	*Notelaea*	*lonifolia*	Large mock-olive		3			6	1.8	6
Elaeocarpaceae	*Elaeocarpus*	*obovatus*	Blueberry ash	6	1	1			1.6	6
Rutaceae	*Acronychia*	*oblongifolia*	Common acronychia				1	6	1.4	6
Casuarinaceae	*Casuarina*	*glauca*	Swamp she-oak	3				3	1.2	3
Lauraceae	*Endiandra*	*globosa*	Black walnut		6				1.2	6
Lauraceae	*Neolitsea*	*dealbata*	White bolly gum		6				1.2	6
Cunoniaceae	*Ceratopetalum*	*gummiferum*	NSW christmas bush				6		1.2	6
Cunoniaceae	*Schizomeria*	*ovata*	Crabapple				6		1.2	6
Mimosaceae	*Acacia*	*maidenii*	Mainden's wattle					6	1.2	6
Mimosaceae	*Archidendron*	*grandifolorum*	Pink lace-flower		3	3			1.2	3
Euphorbiaceae	*Glochidion*	*sumatranum*	Umbrella cheese tree		6				1.2	6
Myrtaceae	*Acema*	*smithii*	Lilli Pilly				3	3	1.2	3
Myrtaceae	*Callistemon*	*salignus*	White bottlebrush					6	1.2	6
Myrtaceae	*Rhodamnia*	*maideniana*	Smooth-leaved brush turpentine		6				1.2	6
Myrtaceae	*Syzygium*	*olersum*	Blue cherry		3		3		1.2	3
Rubiaceae	*Hodgkinsonia*	*ovatiflora*	Golden ash		3		3		1.2	3
Lauraceae	*Cryptocarya*	*obovata*	Pepperberry	1	3	1			1	3
Meliaceae	*Dyoxylum*	*melleri*	Red bean	1	3				0.8	3
Sapindaceae	*Mischocarpus*	*pyiformis*	Brush apple	1	3				0.8	3
Myrtaceae	*Syzygium*	*moorei*	Rose apple	1	3				0.8	3
Araucariaceae	*Araucaria*	*cunninghamii*	Hoop pine	3					0.6	3
Moraceae	*Ficus*	*fraseri*	Sandpaper fig					3	0.6	3
Moraceae	*Ficus*	*watkinsiana*	Strangler fig		3				0.6	3
Atherospermataceae	*Daphnandra*	*micrantha*	Socketwood			3			0.6	3
Lauraceae	*Cryptocarya*	*glaucescens*	Jackwood				3		0.6	3
Lauraceae	*Cryptocarya*	*rigida*	Rose maple				3		0.6	3
Lauraceae	*Endiandra*	*muelleri*	Green-leaved rose walnut		3				0.6	3
Lauraceae	*Endiandra*	*pubens*	White bark walnut			3			0.6	3
Lauraceae	*Endiandra*	*sieberi*	Hard corkwood				3		0.6	3
Escelloniaceae	*Cuttsia*	*viburnea*	Elderberry			3			0.6	3
Pittosporaceae	*Hymenosporum*	*fiavum*	Native frangipani		3				0.6	3
Pittosporaceae	*Pittosporum*	*undulatum*	Sweet pittosporum				3		0.6	3

Suballiance No. 16 *Syzygium luehmannii – Acmena hemilampra*

Site	**Location**
1	Broken Head N.R. & Rec. Reserve
2	luka N.R.
3	Bundagen F.R.
4	Yarrahapinni Ecology Study Centre

				Site				**Av.**	**Max of**
Family	**Genus**	**Species**	**Common**	**1**	**2**	**3**	**4**	**abund. ratings**	**abund. ratings**
Sapindaceae	*Mischocarpus*	*pyiformis*	Brush apple	6	10	6	10	8.0	10
Myrtaceae	*Syzygium*	*luehmannii*	Riberry		10	10	10	7.5	10
Sapindaceae	*Cupaniopsis*	*anacardioides*	Tuckeroo	10	6	10	3	7.3	10
Euphorbiaceae	*Drypetes*	*australasica*	Yellow tulip	3	10	1	6	5.0	10
Rutaceae	*Acronychia*	*imperforata*	Beach acronychia	3	10	3	3	4.8	10
Rutaceae	*Flindersia*	*schottina*	Bumpy ash	3	10		6	4.8	10
Anacardiaceae	*Euroschinus*	*falcata*	Chinaman’s cedar		6	10	3	4.8	10
Moraceae	*Ficus*	*watkinsiana*	Strangler fig		6	6	6	4.5	6
Urticaceae	*Dendrocnide*	*photinophylla*	Shining-leaved stinging tree		6	6	6	4.5	6
Sapindaceae	*Guioa*	*semiglauca*	Guioa	3	6	6	3	4.5	6
Arecaceae	*Archontophoenix*	*cunninghamiana*	Bangalow palm	10	1	3	3	4.3	10
Rubiaceae	*Hodgkinsonia*	*ovatiflora*	Golden ash	10	1	3	3	4.3	10
Podocacarpaceae	*Podocarpus*	*elatus*	Brown pine	1	3	6	6	4.0	6
Ulmaceae	*Aphananthe*	*philippinensis*	Native elm	10			6	4.0	10
Proteaceae	*Banksia*	*integrifolia*	Coast banksia	3	3	10		4.0	10
Celastraceae	*Cassine*	*australis*	Red olive berry	3	6	6	1	4.0	6
Sapindaceae	*Arytera*	*divaricara*	Coogara		10	3	3	4.0	10
Myrtaceae	*Acema*	*hemilampra*	Broad-leaved lilly pilly	6	10			4.0	10
Rubiaceae	*Canthium*	*coprosmoides*	Coast canthium	6	6	1	3	4.0	6
Myrtaceae	*Rhodomyrtus*	*psidioides*	Native guava	3	3	3	6	3.8	6
Myrtaceae	*Syzygium*	*olersum*	Blue cherry	3	6	3	3	3.8	6
Oleraceae	*Notelaea*	*lonifolia*	Large mock-olive		6	3	6	3.8	6
Ebenaceae	*Diospyros*	*pentamera*	Grey persimon		10	3	1	3.5	10
Euphorbiaceae	*Glochidion*	*ferdinandi*	Cheese tree	6	3	1	3	3.3	6
Lauraceae	*Litsea*	*australis*	Brown bolly gum	3	3	3	3	3.0	3
Rutaceae	*Flindersia*	*bennettiana*	Bennett’s ash	6	6			3.0	6
Rutaceae	*Halfordia*	*kendack*	Saffronheart	6	6			3.0	6
Sapindaceae	*Alectryon*	*coniaceus*	Beach bird’s eye		6	6		3.0	6
Myrtaceae	*Lophostemon*	*confertus*	Brush box	3	3	3	3	3.0	3
Moraceae	*Ficus*	*coronata*	Creek sandpaper fig		1	3	6	2.5	6
Moraceae	*Ficus*	*fraseri*	Sandpaper fig	3	3	1	3	2.5	3
Myrtaceae	*Rhodamnia*	*argentea*	Malletwood		6		3	2.3	6
Epacridaceae	*Trochocarpa*	*laurina*	Tree heath		3	3	3	2.3	3
Myrtaceae	*Acema*	*smithii*	Lilli Pilly		1	6	1	2.0	6
Araliaceae	*Polyscias*	*legans*	Celery wood	3	1	3	1	2.0	3
Ulmaceae	*Celtis*	*paniculata*	Native hackberry		3	1	3	1.8	3
Moraceae	*Ficus*	*obliqua*	Small-leaved fig		3	3	1	1.8	3
Lauraceae	*Endiandra*	*discolor*	Rose walnut		1	6		1.8	6
Euphorbiaceae	*Claoxylon*	*australe*	Brittlewood		6	1		1.8	6
Myrtaceae	*Syzygium*	*australe*	Brush cherry	1		6		1.8	6
Araucariaceae	*Araucaria*	*cunninghamii*	Hoop pine	6				1.5	6
Arecaceae	*Livistona*	*australis*	Cabbage tree palm		3		3	1.5	3
Lauraceae	*Cryptocarya*	*triplinervis*	Three veined laurel	3	3			1.5	3

Suballiance No. 24 *Castanospermum – Grevillea robusta*

Site	**Location**
1	Sawpit Ck., Border Ranges N.P.
2	Moore Park Rec. Reserve
3	Yorklea, Freehold

					Site			
Family	**Genus**	**Species**	**Common**	**1**	**2**	**3**	**Av. abund. ratings**	**Max of abund. ratings**
Fabaceae	*Castanospermum*	*australe*	Black bean	6	10	10	8.7	10
Casuarinaceae	*Casuarina*	*cunninghamiana*	River oak		10	6	5.3	10
Ulmaceae	*Aphananthe*	*philippinensis*	Native elm	3	10	3	5.3	10
Euphorbiaceae	*Baloghia*	*inophylla*	Brush bloodwood	6	10		5.3	10
Moraceae	*Ficus*	*coronata*	Creek sandpaper fig	6	6	3	5.0	6
Proteaceae	*Grevillea*	*robusta*	Silky oak	3	10	1	4.7	10
Euphorbiaceae	*Malotus*	*philippensis*	Orange kamalla	3	6	3	4.0	6
Myrtaceae	*Syzygium*	*australe*	Brush cherry	6	3	3	4.0	6
Myrtaceae	*Syzygium*	*francisii*	Giant water-gum	10	1		3.7	10
Podocacarpaceae	*Podocarpus*	*elatus*	Brown pine		10		3.3	10
Moraceae	*Streblus*	*brunonianus*	Whalebone tree	3	6	1	3.3	6
Myrtaceae	*Eucalyptus*	*grandis*	Flooded gum	10			3.3	10
Myrtaceae	*Melaleuca*	*bracteata*	White cloud tree		10		3.3	10
Atherospermataceae	*Daphnandra*	*micrantha*	Socketwood	6	3		3.0	6
Mimosaceae	*Acacia*	*concurrens*	Curracabah		6	3	3.0	6
Surianaceae	*Guifoylia*	*monostylis*	Native plum	6	3		3.0	6
Sapindaceae	*Arytera*	*divaricara*	Coogara	6	3		3.0	6
Lauraceae	*Beilschmiedia*	*elliptica*	Grey walnut	1	6		2.3	6
Lauraceae	*Cryptocarya*	*obovata*	Pepperberry	3	3	1	2.3	3
Lauraceae	*Cryptocarya*	*triplinervis*	Three veined laurel		1	6	2.3	6
Meliaceae	*Toona*	*australis*	Red cedar	6	1		2.3	6
Urticaceae	*Dendrocnide*	*excelsa*	Giant stinging tree	6			2.0	6
Lauraceae	*Beilschmiedia*	*obtusifolia*	Hard bolly gum	3	3		2.0	3
Mimosaceae	*Pararchidendron*	*pruinosum*	Snow-wood		6		2.0	6
Meliaceae	*Dyoxylum*	*fraserianum*	Rosewood	6			2.0	6
Meliaceae	*Melia*	*azedarach* var. *australasica*	White cedar	3	3		2.0	3
Sapindaceae	*Elattostachys*	*nervosa*	Beetroot	6			2.0	6
Sterculiaceae	*Argyrodendron*	*actinophyllum*	Black booyong	6			2.0	6
Sterculiaceae	*Argyrodendron*	*trifoliolatum*	White booyong	6			2.0	6
Myrtaceae	*Acema*	*smithii*	Lilli Pilly			6	2.0	6
Myrtaceae	*Callistemon*	*viminalis*	Drooping bottlebrush		3	3	2.0	3
Moraceae	*Ficus*	*macrophylla*	Moreton bay fig	3	1		1.3	3
Rutaceae	*Acronychia*	*oblongifolia*	Common acronychia		1	3	1.3	3
Sapindaceae	*Alectryon*	*subcinereus*	Wild quince	3	1		1.3	3
Sapindaceae	*Diploglottis*	*australis*	Tamarind	3	1		1.3	3
Sapindaceae	*Guioa*	*semiglauca*	Guioa	3	1		1.3	3
Ulmaceae	*Celtis*	*paniculata*	Native hackberry		3		1.0	3
Urticaceae	*Dendrocnide*	*photinophylla*	Shining-leaved stinging tree	3			1.0	3
Lauraceae	*Endiandra*	*muelleri*	Green-leaved rose walnut	1	1	1	1.0	1
Lauraceae	*Litsea*	*australis*	Brown bolly gum	3			1.0	3
Lauraceae	*Neolitsea*	*australiensis*	Smooth-barked booly gum	3			1.0	3
Lauraceae	*Neolitsea*	*dealbata*	White bolly gum		3		1.0	3
Pittosporaceae	*Hymenosporum*	*flavum*	Native frangipani		3		1.0	3

Suballiance No. 33 *Ceratopetalum/Schizomeria – Argyrodendron/Sloanea*

Site	**Location**
1	Hogans Scrub, Freehold
2	Middle Ck., F.R., Marengo S.F.
3	Bruxner Park F.R., Orara East S.F.
4	Waterfall and Cockerawombeeba Cks., Mt. Boss S.F.
5	Weelah N.R.

Family	**Genus**	**Species**	**Common**			**Site**			**Av. abund. ratings**	**Max of abund. ratings**
				1	**2**	**3**	**4**	**5**		
Elaeocarpaceae	*Sloanea*	*woollsii*	Yellow carabeen	3	10	10	10	3	7.2	10
Cunoniaceae	*Geissois*	*benthamii*	Red carabeen	1	3	6	10	6	5.2	10
Sterculiaceae	*Argyrodendron*	*actinophyllum*	Black booyong		10	3	6	6	5	10
Atherospermataceae	*Doryphora*	*sassafras*	Sassafras	6	6	3	6	3	4.8	6
Cunoniaceae	*Ceratopetalum*	*apetalum*	Coachwood	10	3	10			4.6	10
Arecaceae	*Archontophoenix*	*cunninghamiana*	Bangalow palm	10		10			4	10
Lauraceae	*Cryptocarya*	*meissneriana*	Thick-leaved laurel	3			10	6	3.8	10
Escelloniaceae	*Polyosma*	*cunninghamii*	Featherwood	3	3	6	3	3	3.6	6
Cunoniaceae	*Caldcluvia*	*paniculosa*	Corkwood	3	3	3	3	6	3.6	6
Lauraceae	*Cryptocarya*	*microneura*	Murrogun	3		6	1	6	3.2	6
Elaeocarpaceae	*Sloanea*	*australis*	Mainden's blush	6		10			3.2	10
Moraceae	*Ficus*	*coronata*	Creek sandpaper fig		6	3	6		3	6
Proteaceae	*Orites*	*excelsa*	Prickly ash	3	6	3	3		3	6
Cunoniaceae	*Schizomeria*	*ovata*	Crabapple		3	3	3	6	3	6
Meliaceae	*Synoum*	*glandulosum*	Scentless rosewood	3		3	3	6	3	6
Myrtaceae	*Lophostemon*	*confertus*	Brush box	6		6	3		3	6
Ebenaceae	*Diospyros*	*pentamera*	Grey persimon	3	3	6		3	3	6
Moraceae	*Ficus*	*watkinsiana*	Strangler fig	3		10		1	2.8	10
Lauraceae	*Cryptocarya*	*glaucescens*	Jackwood	6	1	3	1	3	2.8	6
Epacridaceae	*Trochocarpa*	*laurina*	Tree heath	3	1	3	1	6	2.8	6
Escelloniaceae	*Quintinia*	*verdonii*	Grey possumwood	3		6	1	3	2.6	6
Rutaceae	*Acradenia*	*euodiiformia*	Bonewood			10	3		2.6	10
Euphorbiaceae	*Baloghia*	*inophylla*	Brush bloodwood				3	10	2.6	10
Myrtaceae	*Acema*	*smithii*	Lilli Pilly	6	1		3	3	2.6	6
Atherospermataceae	*Daphnandra*	*micrantha*	Socketwood		1		1	10	2.4	10
Lauraceae	*Cryptocarya*	*rigida*	Rose maple			6	3	3	2.4	6
Icacinaceae	*Pennan??a*	*cunninghamii*	Brown beech		6		3	3	2.4	6
Sapindaceae	*Guioa*	*semiglauca*	Guioa	3		3		6	2.4	6
Rhamnaceae	*Alphitonia*	*excelsa*	Red ash	6		6			2.4	6
Myrtaceae	*Rhodamnia*	*rubescens*	Scub turpentine	3		6		3	2.4	6
Lauraceae	*Neolitsea*	*dealbata*	White bolly gum	3		6	1	1	2.2	6
Sapindaceae	*Diploglottis*	*australis*	Tamarind	3	1	3	1	3	2.2	3
Sapindaceae	*Sarcopteryx*	*stipata*	Steelwood	3	1	3	1	3	2.2	3
Lauraceae	*Endiandra*	*muelleri*	Green-leaved rose walnut	3		3	1	3	2	3
Elaeocarpaceae	*Elaeocarpus*	*reticulatus*	Lily-of-the-valley tree	3		3	1	3	2	3
Lauraceae	*Endiandra*	*discolor*	Rose walnut	6		3			1.8	6
Myrtaceae	*Eucalyptus*	*grandis*	Flooded gum	3		6			1.8	6
Urticaceae	*Dendrocnide*	*excelsa*	Giant stinging tree	1	1		3	3	1.6	3
Proteaceae	*Stenocarpus*	*salignus*	Scrub beefwood	1		3	1	3	1.6	3
Meliaceae	*Dyoxylum*	*fraserianum*	Rosewood	1	3		1	3	1.6	3
Euphorbiaceae	*Claoxylon*	*australe*	Brittlewood		1	3	1	3	1.6	3
Sapotaceae	*Planchonella*	*australis*	Black apple	3		3	1	1	1.6	3
Verbenaceae	*Gmelina*	*leichhardtii*	White beech	1		3	1	3	1.6	3

Appendix 5. List of species from the brushes of the Richmond River region, as printed in the *Clarence and Richmond Examiner* and *New England Advertiser*, 1 April, 1873, p. 6.

The likely current names were based on the original botanical name utilising the Australian Plant Census and Australian Plant Name Index.

Botanical name (1873)	**Local name**	**Height**		**Likely current botanical name**
		Feet	**Metres**	
Eucaliptus sideroploia	Ironbark	100–50	30–45	*Eucalyptus siderophloia*
Eucaliptus rostrata	Flooded gum	100–50	30–45	*Eucalyptus camaldulensis*
Eucaliptus saligna	Grey gum	100–50	30–45	*Eucalyptus saligna*
Eucaliptus amygdalina	Stringybark	80–50	24–45	*Eucalyptus amygdalina*
Eucaliptus robusta	Mahogany	100–50	30–45	*Eucalyptus robusta*
Eucaliptus maculate	Spotted gum	80–20	24–37	*Corymbia maculata*
Eucaliptus corymbosa	Bloodwood	70–20	21–37	*Corymbia gummifera*
Backhousia myrtifolia	–	40	12	*Backhousia myrtifolia*
Eugenia ventenatii	Water gum	70–90	21–27	*Syzygium floribundum*
Eugenia jambolana	Durobby	80–00	24–30	*Syzygium cumini*
Eugenia myrtifolia	Brush cherry	30–80	9–24	*Syzygium australe*
Eugenia sp.	Coolmin	100–50	30–45	
Myrtus Becklerii	Myrtle	60–80	18–24	*Archirhodomyrtus beckleri*
Myrtus Acmenioides	White myrtle	60–80	18–24	*Gossia acmenoides*
Rhodamnia trinervia	Three-veined myrtle	30–40	9–12	*Rhodamnia rubescens*
Callistemon salignus	Broad-leaved tea tree	60–80	18–24	*Callistemon salignus*
Malaleuca styphellioides	Fine-leaved tea tree	30–40	9–12	*Melaleuca styphelioides*
Malaleuca leucadendron	White tea tree	50–80	15–24	*Melaleuca leucadendra*
Malaleuca armillaris	Small tea tree	20–30	6–9	*Melaleuca armillaris*
Tristania conferta	Bastard box	80–30	24–40	*Lophostemon confertus*
Tristania suavolens	Swamp mahogany	80–20	24–37	*Lophostemon suaveolens*
Tristania neriifolia	Water gum	80–00	24–30	*Tristania neriifolia*
Cedrela Australis	Red cedar	100–60	30–49	*Toona ciliata*
Flindersia Greaveaii	Bulbura	100–60	30–49	*??*
Flindersia Australis	Cudgery	80–00	24–30	*Flindersia australis*
Flindersia Oxleyana	Yellow wood	80–00	24–30	*Flindersia xanthoxyla*
Flindersia Schottiana	White wood	80–00	24–30	*Flindersia schottiana*
Flindersia Bennettiana	Bogum	80–00	24–30	*Flindersia bennettiana*
Dysoxylon Fraseranum	Rosewood	80–100	24–30	*Dysoxylum fraserianum*
Dysoxylon Mullerii	Pencilwood	80–100	24–30	*Dysoxylum mollissimum*
Dysoxylon rufum	–	40–50	12–15	*Dysoxylum rufum*
Melia composite	White cedar	40–60	12–18	*Melia azedarach*
Acacia Cunninghamii	Bastard myall	30–40	9–12	*Acacia trinervata*
Acacia glaucescens	–	50–70	15–21	*Acacia binervia*
Castanospermum Australe	Beantree	100–130	30–40	*Castanospermum australe*
Castanospermum decurrens	Green wattle	30–40	9–12	*??*
Pithecolobium pruinosum	A yellow wood	30–50	9–15	*Pararchidendron pruinosum*
Monotoca elliptica	Sea coast box	Handles		*Monotoca elliptica*
Echinocarpus Australis	–	100–150	30–45	*Sloanea australis*
El??ocarpus grandis	Blue peach	50–80	15–24	*Elaeocarpus grandis*
Sloanea Australis	Maiden's blush	30–40	9–12	*Sloanea Australis*
Elcodendron Australe	–	30	9	*Elaeodendron australe*
Aracuaria Cunninghamii	Moreton Bay pine	100–180	30–55	*Araucaria cunninghamii*
Frenela columnaris	Cypress pine	50–80	15–24	*Callitris columellaris*
Grevillea robusta	Silky oak	60–80	18–24	*Grevillea robusta*
Stenocarpus salignus	Beef wood	60–80	18–24	*Stenocarpus salignus*
Stenocarpus sinuatus	–	80–100	24–30	*Stenocarpus sinuatus*
Banksia serrata	Honeysuckle	30–50	9–15	*Banksia serrata*
Doryphora sassafras	Sassafras	70–80	21–24	*Doryphora sassafras*
Daphandra micrantha	Light yellow wood	70–90	21–27	*Daphnandra micrantha*
Harpullia pendula	Tulip wood	30–40	9–12	*Harpullia pendula*
Diploglottis Cunninghamii	Native tamarind	60–90	18–27	*Diploglottis australis*
Cupania pseudorhus	Light yellow wood	50–80	15–24	*Jagera pseudorhus*
Achras Australias	Black apple	60–100	18–30	*Planchonella australis*
Ber?ali?ia sp.	–	90–100	27–30	
Alphitonia excelsa	–	70–100	21–30	*Alphitonia excelsa*
Cryptocarya glauceacens	Laurel	80–100	24–30	*Cryptocarya glaucescens*
Cryptocarya obvata	Sycamore	80–100	24–30	*Cryptocarya obovata*
Tetranthera ferrugina	–	80	24	*Litsea breviumbellata ??*
Weinmanni sp.	Murraree	100–150	30–45	*Pseudoweinmannia lachnocarpa*
Grissois Benthemii	–	100–120	30–37	*Geissois benthamiana*

Avicennia tomentose	Large mangrove	30–50	9–15	*Avicennia marina*
Gmelina Leichardtii	Beech	100–150	30–45	*Gmelina leichhardtii*
Casaurina tennissima	Forest oak	50–80	15–24	*Allocasuarina torulosa*
Casaurina quadrivalvis	Swamp oak	40–90	12–27	*Allocasuarina verticillata*
Baloghia lucida	Brush bloodwood	40	12	*Baloghia inophylla*
Bradleia Australis	Red wood	50–70	15–21	*??*
Cargillia pentamera	Black myrtle	80–100	24–30	*Diospyros pentamera*
Celtis op?ca	–	40–60	12–18	*??*
Duboisra myoporoides	Cork wood	50	15	*Duboisia myoporoides*
Memecyclon sp.	Brush cherry, cobbinmuni	60–80	18–24	*Memecylon* sp. *??*
Myrsine varabilis	–	20–50	6–15	*Myrsine variabilis*
Pittisporum undulatum	–	30–40	9–12	*Pittosporum undulatum*
Podocarpus spinulosus	Smooth bark pine	40–120	12–37	*Podocarpus spinulosus*
Tarrietia actinodendron	Stave wood	70–120	21–37	*??*
Tarrietia argyrodendron	Iron wood	100–150	30–45	*??*
Tarrietia Carronii	Byong	100–150	30–45	*Argyrodendron trifoliolatum ??*
Rhus rodanthema	Dark yellow wood	50–80	15–24	*Rhodosphaera rhodanthema*

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Acacia pendula (Weeping Myall) in the Hunter Valley of New South Wales: early explorers' journals, database records and habitat assessments raise doubts over naturally occurring populations

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Abstract: *Acacia pendula*, Weeping Myall, (family Fabaceae) is the most legislatively protected plant species in the New South Wales Hunter Valley. Under the NSW *Threatened Species Conservation Act 1995* it is listed as an Endangered Population (in the Hunter Valley) and as a component of two Endangered Ecological Communities (one in the Hunter, one elsewhere in NSW); it is also listed as a Critically Endangered Ecological Community (in the Hunter Valley) on the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* and listed as threatened in three other eastern Australian States.

To ascertain the likely original distribution of stands of *Acacia pendula* in the Hunter Valley, this paper examines the writings of early Australian explorers, herbarium and database records, and the species habitat attributes across NSW. None of the journals examined, including those of botanist/explorer Allan Cunningham (who originally collected *Acacia pendula* from the Lachlan River in 1817), Thomas Mitchell or Ludwig Leichhardt, make note of the species for the Hunter Valley. Several explorers do, however, record *Acacia pendula* regularly (>100 times) across other parts of NSW, Queensland, and South Australia.

Historical herbarium and database records show a paucity of records from the Hunter prior to the year 2000, after which a 37-fold increase in observations since 1951 is apparent. For the first 128 years of botanical exploration (1823 to 1951), there are no validated collections or records of *Acacia pendula* from the Hunter Valley. The single exception is a specimen collected by Cunningham from 1825 (lodged at Kew, UK), purported to be from 'Hunters River', but which is morphologically different to other collections of *Acacia pendula* from that time. There is some uncertainty over the origins of this specimen.

Analysis of habitats supporting *Acacia pendula* in NSW outside of the Hunter show them to differ significantly in geological age, soil type, rainfall and elevation from those in the Hunter.

Collectively, these findings provide a strong circumstantial case that *Acacia pendula* was absent from the Hunter at the time of European settlement; this has important implications for the conservation and management of Hunter stands. Rather than being a threatened species in the Hunter Valley, it is postulated that *Acacia pendula* has been intentionally and/or accidentally introduced to the region, and may now be imposing a new and emerging threat to the endangered grassy woodlands and forests there. There is now an urgent need for genetic studies to clarify the origins of the current Hunter Valley stands, and to define the taxonomic limits of *Acacia pendula* and its close relatives.

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Introduction

”I rode up the creek about three quarters of a mile, and came upon those extensive plains before-mentioned … covered with a great variety of new plants, …. encircled by a new species of Acacia, which received the specific name of pendula, from its resembling in habit the weeping willow”.

So wrote explorer John Oxley on May 5th 1817, while in country west of Bathurst in central western New South Wales (Oxley 1820). *Acacia pendula* A.Cunn Ex G.Don or Weeping Myall as it is now commonly referred to, is a tall, graceful shrub or small tree widespread in the interior regions of eastern Australia. It is indeed characterised by the grey-green, pendulous foliage that is reminiscent of Weeping Willows (*Salix babylonica*). With Oxley was Allan Cunningham, the King’s botanist, and it was he who collected the type of *Acacia pendula* from the Lachlan River. The formal description of the species was later included in the work of Don (1832), some fifteen years after Cunningham had first encountered it. Despite a long history of revisions within the *Acacia* genus (Maslin et al. 2003), the name and integrity of *Acacia pendula* has remained intact for over 190 years.

Acacia pendula (family Fabaceae) is well known from inland New South Wales and Queensland, where it occurs on major river floodplains on heavy clay soils (Stanley & Ross 1995; Kodela & Harden 2002), in Victoria from a few small, degraded stands (Venn 2004), and the extreme eastern part of South Australia (Cowan 2001). The upper Hunter Valley of NSW is reportedly the eastern distributional limit for the species (Kodela & Harden 2002), although in recent years it has become unclear how far east the species actually extends into this region. Taxonomically, the *Acacia pendula–melvillei–homalophylla* species group is complex and has not yet been satisfactorily resolved. Fensham & Fairfax (1997) documented how identities of these three taxa have been confused in the past, and many botanists now simply refer to an ‘*Acacia melvillei–homalophylla* species complex’ in recognition of the difficulties of separating the latter two taxa. *Acacia homalophylla* is also very closely related to both *Acacia melvillei* and *Acacia pendula* (Cowan & Maslin 2001), and as a consequence it is understandable that problems in identification still exist. Other species of Myall in the Hunter Valley (e.g. *Acacia binervia*) are distinguished from this group primarily by floral arrangement.

Taxonomic uncertainty in the populations of *Acacia pendula* within the Hunter Valley, including recognition of two forms (pendulous and non-pendulous habit, Table 1) that have been identified as this species over the last fifteen years, has been previously highlighted (Umwelt 2006a; Bell et al. 2007). This uncertainty is due to the uncharacteristic appearance of many of the trees in this region (the non-pendulous forms), and the lack of fertile fruit production needed to positively identify the species. For conclusive separation between *Acacia pendula* and its close relatives (*Acacia melvillei, Acacia homolophylla*), seed arrangement within fertile pods together with floral characters are necessary (Cowan 2001; Kodela & Harden 2002). In the Hunter Valley, pod development progressing to mature seed has only been observed for the pendulous forms of *Acacia pendula*, while non-pendulous forms have never achieved this state (Bell 2007). Arguably, some of the non-pendulous forms of *Acacia pendula* may in fact represent forms or hybrid swarms of *Acacia melvillei–Acacia homalophylla*, which may or may not be native to the Hunter, while pendulous forms may have been planted: these issues are addressed later in this paper.

Within Commonwealth and State threatened species legislation, *Acacia pendula* is protected variously as a species, population and ecological community across several jurisdictions, making it one of the most protected plant species in the country. Nationally, the *Environment Protection and Biodiversity Conservation Act 1999* includes *Acacia pendula* as a key species in the Endangered *Weeping Myall Woodlands* and the Critically Endangered *Weeping Myall–Coobah–Scrub Wilga Shrubland of the Hunter Valley*. Under New South Wales *Threatened Species Conservation Act 1995* legislation, an Endangered Population of *Acacia pendula* is listed within the Hunter Valley (*Acacia pendula, a tree, in the Hunter catchment*). The species also forms a key component of the Endangered *Hunter Valley Weeping Myall Woodland*. Elsewhere in New South Wales, *Acacia pendula* is a characteristic species in the Endangered *Myall Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain, Murray-Darling Depression, Riverina and NSW South Western Slopes Bioregions*. Because of separate state responsibilities, *Acacia pendula* is listed as a vulnerable species on the *Flora and Fauna Guarantee Act 1988* in Victoria and the *National Parks and Wildlife Act 1972* in South Australia. *Acacia pendula* is considered to be of Least Concern in the international IUCN Red List of Threatened Species due to its widespread distribution (Malcolm 2012).

Table 1. Morpho-types of Hunter Valley *Acacia pendula* recognised in this paper.

Morpho-type	**Characteristics**
A	Small tree with grey-green or glaucous foliage; pendulous (weeping) branches; flowers and fruits freely; very occasionally root suckering
B	Small tree with green foliage; slightly pendulous branches on older specimens; flowers but soon becoming infested by gall; never fruits successfully; commonly root suckering
C	Small tree with green foliage; non-pendulous foliage, rounded canopy; rarely flowers, but then soon infested by gall; never fruits successfully; vigorous root suckering

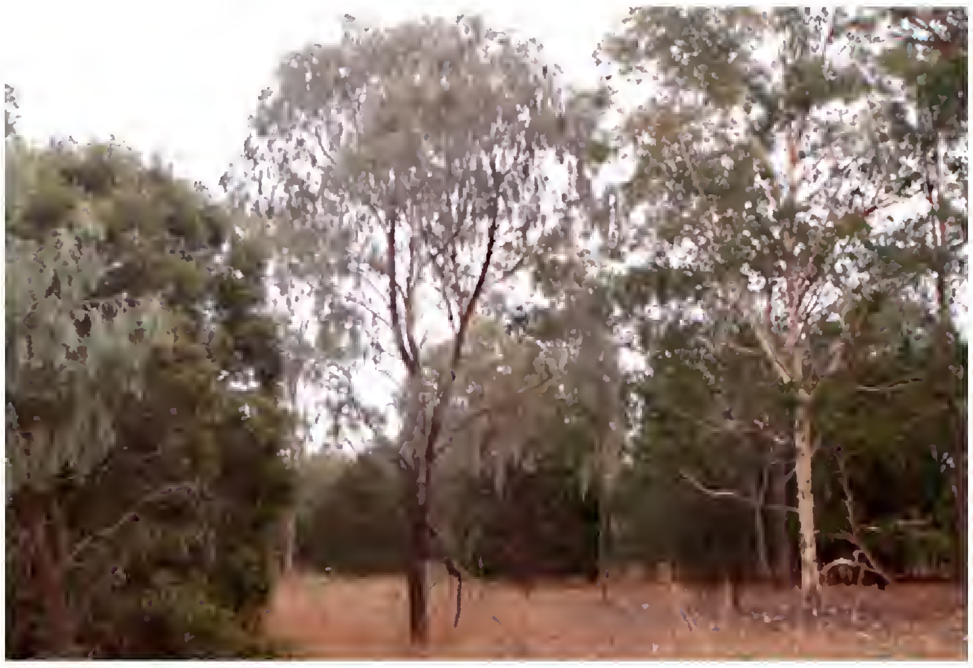

Fig. 1a. Morpho-type A (Muswellbrook)

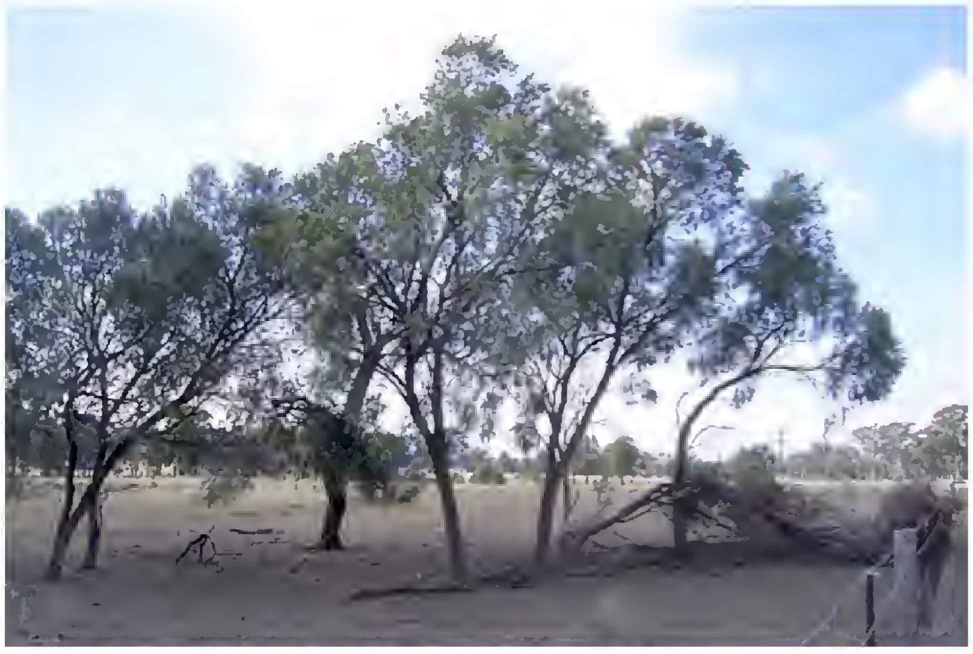

Fig. 1b. Morpho-type B (Wybong)

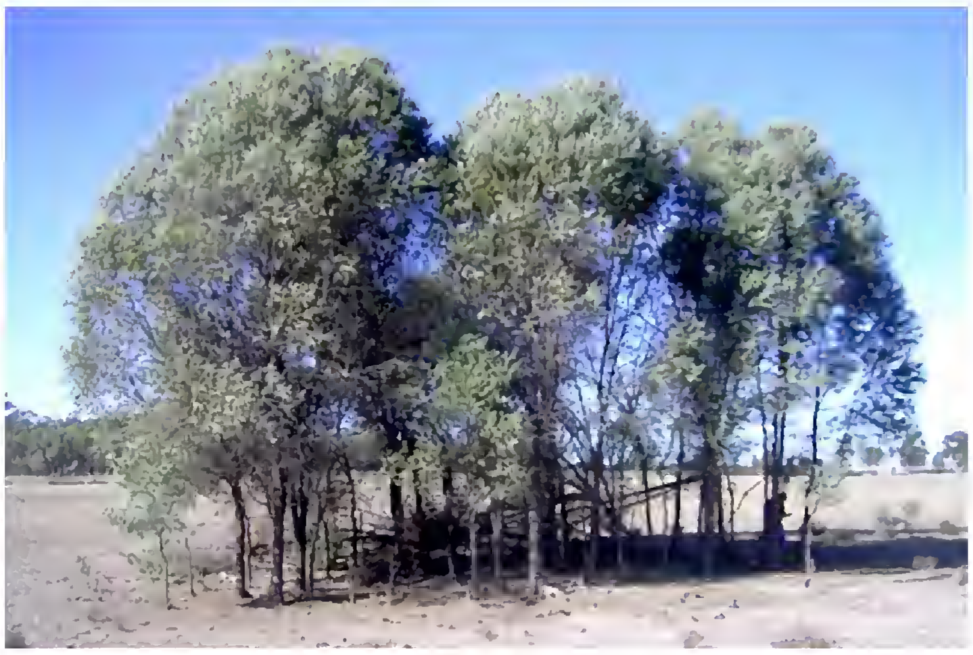

Fig. 1c. Morpho-type C (Warkworth)

Fig. 1 a-c. Morpho-types of *Acacia pendula* recognised in this paper for the Hunter Valley.

Surprisingly, VICDSE (2009) includes *Acacia pendula* in the low risk category of their environmental weed list for the Inland Plains bioregion, contrasting with its listing as vulnerable in that State.

This paper questions the presence of *Acacia pendula* as a ‘naturally occurring’ species in the region (i.e. present within the Hunter prior to pre 1788 European settlement) through three avenues of evidence. Firstly we review the writings of early Australian explorers both within and outside of the Hunter. Secondly we assess database and herbarium records in an attempt to clarify the distributional extent of this species within the Hunter Valley. Thirdly, assessments of habitat in areas currently reported to support the species are compared to documented habitat elsewhere in the range of the species. For clarity of discussion, and given the taxonomic uncertainties of Hunter specimens (Bell et al. 2007), three morpho-types (following Miller et al. 2002 for *Acacia aneura*) are defined, as different issues apply to each. These three morpho-types (Table 1, Figure 1) are readily recognisable in the field primarily on the basis of habit and canopy colour, and are often used by field ecologists and managers to differentiate observable forms. Throughout this paper, unless otherwise noted, *Acacia pendula* is applied broadly to encompass all three of these morpho-types, and is consistent with identification advice for Hunter Valley plants received from the National Herbarium of New South Wales over the past fifteen years.

Study Area

The Hunter Valley is a large coastal catchment in central eastern New South Wales (Figure 2), and one of only two low relief incursions across the Great Dividing Range. This region includes two major rivers, the Hunter and the Goulburn, which converge near Muswellbrook and flow east to the coast at Newcastle. The Hunter catchment includes all of the Goulburn, and together the two rivers comprise 21,460 km^2 of diverse land uses including agriculture, urban, conservation, industrial and mining. Historically, the bulk of the valley floor and undulating slopes have been cleared for stock grazing, but in recent decades coalmining has taken up increasingly more agricultural land.

For context, it is necessary to understand the process of European settlement in the Hunter. The Hunter Valley was one of the first regions outside Sydney to be explored for arable lands, and its opening up to European settlement came from the sea via the Hunter River, and overland from Sydney (Jervis 1953a,b; Perry 1955; McMinn 1970a). In 1797 Lieutenant John Shortland charted what is now Newcastle Harbour, at the mouth of the Hunter River, followed by William Paterson in 1801 who journeyed inland along the Hunter River to near the present site of Maitland, where he and his party explored the Paterson River to around Woodville. Over a decade later, between 1817 and 1819, several explorers tried to cross the rugged country (now including the wilderness areas of Wollemi and Yengo National Parks) between the Cumberland Plain (Sydney) and the Hunter Valley. These included William Parr, Benjamin Singleton and John Howe; in 1819 Howe and his men were the first to descend out of the rugged ranges to the Hunter Valley floor, between Jerrys Plains and Denman.

Exploration of the upper Hunter Valley was also carried out from two directions; expeditions extended up the Valley from the east, and others, on the western side of the Blue Mountains, headed north and east from Bathurst. In 1822, William Lawson headed north from Bathurst in a failed attempt to find a route onto the Liverpool Plains, (which John Oxley had traversed from the west in 1818). Somewhere between Gulgong and Ulan, on the extreme west of the Hunter catchment, Lawson happened upon the Goulburn River, a major tributary of the Hunter. In 1823 Allan Cunningham, government botanist, searched for a pass onto the Liverpool Plains, and over the following four years made three other journeys through parts of the Hunter Valley. William Lee explored further south of Cunningham's 1823 traverse, between Denman and the headwaters of the Goulburn River in 1827.

Meanwhile in 1824, government surveyor Henry Dangar explored the land west and north of Singleton linking up the known lands of the upper and lower Hunter Valley. He reached the headwaters of Dart Brook near Scone and a pass over the Liverpool Range. In 1827, William Nowland discovered an easier route across the Liverpool Range, the Ardglen Gap near the present town of Murrurundi.

Methods

Early explorers journals

The journals of early botanical explorers are often used to elucidate vegetation patterns occurring at the time of European settlement in Australia (e.g. Benson & Redpath 1997; Fensham et al. 2006; Lang 2008; Moxham et al. 2009). *Acacia pendula* was collected and described in 1817, before exploration in the Hunter, and it is entirely plausible that some reference to this species, if present in the Hunter, would appear in some or all of the subsequent journals of early Australian explorers. This is particularly so because such an occurrence would be novel so far east from where it was known to be abundant. The aesthetically pleasing appearance of *Acacia pendula* trees (both individually and where it dominates a landscape) greatly aids this expectation, as early explorers often wrote about attractive landscapes.

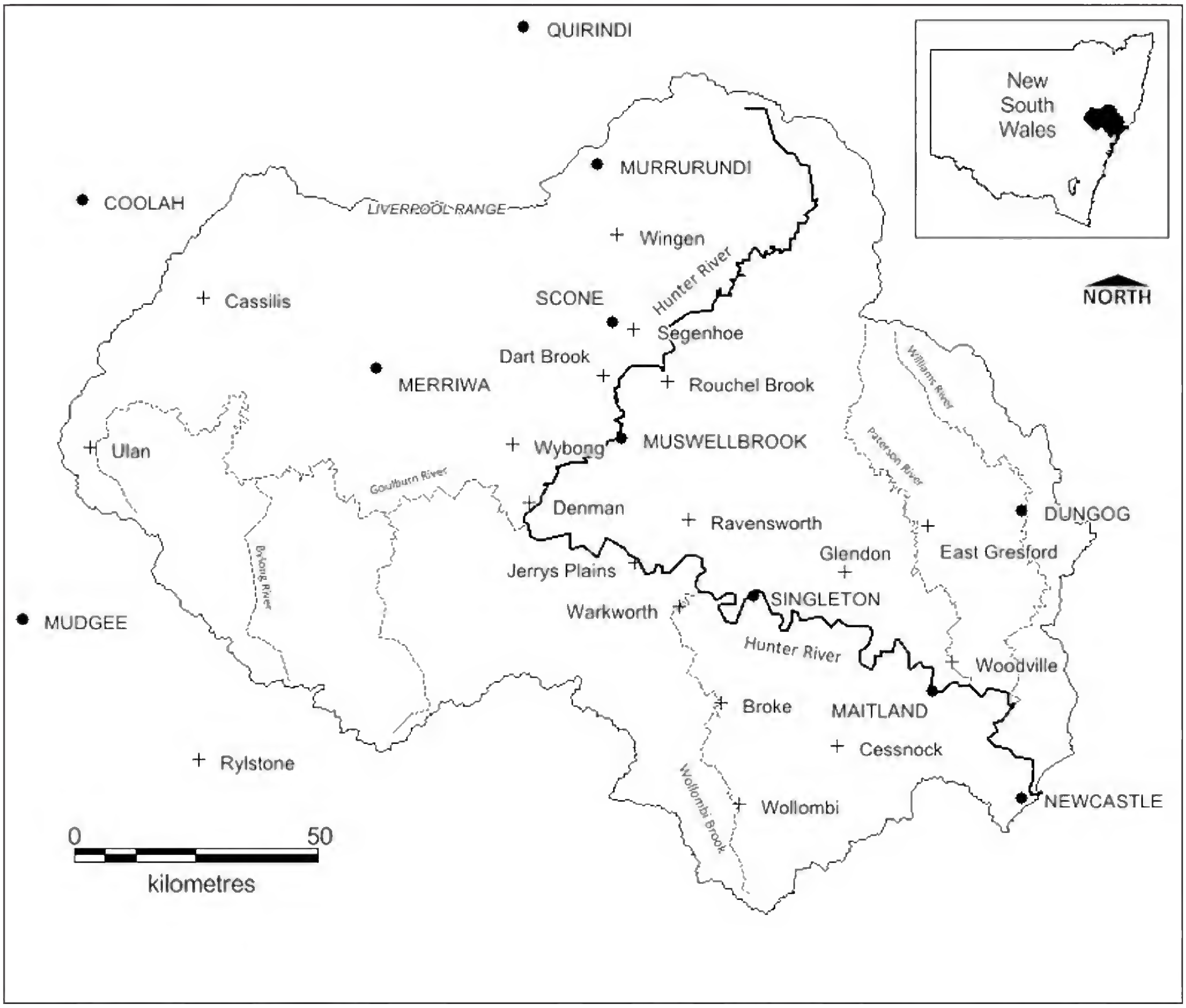

Fig. 2. The Hunter Valley in eastern New South Wales, showing waterways and locations mentioned in the text.

Expedition journals or transcriptions of the early Australian explorers who first entered the Hunter, including those with botanical expertise such as Allan Cunningham, Thomas Mitchell and Ludwig Leichhardt, were examined for indications of the state of natural vegetation prior to European settlement. For Allan Cunningham, copies of his original journal entries were examined (Cunningham 1832a), as well as other publications (Cunningham 1825, 1828, 1832b) and the edited transcripts and commentaries contained in Lee (1925) and McMinn (1970a,b). Full accounts of the travels of Mitchell are contained in his manuscript (Mitchell 1838), while for Leichhardt the transcriptions of Aurousseau (1968) and Darragh and Fensham (2013) were the primary sources. Explorer's journals for expeditions elsewhere in Australia, but within the known range of *Acacia pendula*, have also been consulted to ascertain the extent to which this species was mentioned there. These include the online versions of writings and expeditions of John Oxley, George Evans, Charles Sturt, Thomas Mitchell, Edward John Eyre, Ludwig Leichhardt, William Landsborough, and several others. Other writings by early settlers, journalists and historical scholars have also been examined, including contemporary treatments of the spread of settlement and agricultural pursuits up until the present day.

Database and herbarium records

While historical journals provide important commentary on the lands explored during the 1800s, specimen collections and (more recently) digital database records of *Acacia pendula* provide more tangible evidence on the species distribution. Specimen collection details and digital databases were searched for *Acacia pendula* from two online data sources, Australia's Virtual Herbarium (AVH: http://avh.chah.org.au/) and the NSW Office of Environment & Heritage's BioNet Atlas of Wildlife (BioNet: http://www.bionet.nsw.gov.au/). The AVH is a collaboration between all nine major herbaria in Australia, and seeks to make available collection locations and notes of all Australian plant collections. Currently, over six million specimens are included in AVH. Some important historical collections (such as those of Allan Cunningham) are housed in the Kew Herbarium (London), and were searched directly from there. BioNet is a portal for accessing government-held information about plants and animals in NSW, and is supported by several NSW government agencies. BioNet is not a specimen register, but stores locality records as submitted by government and private individuals. Additional locality records for *Acacia pendula* not yet included in either of these two data sources were obtained from colleagues working in the Hunter Valley area.

All specimen and database records both for the Hunter Valley and the rest of NSW and Australia were examined in a Geographical Information System (GIS), to gain an appreciation of the historical distribution of this species. Where possible, all locations of *Acacia pendula* within the Hunter have been examined in the field by us, but in some cases the advice of colleagues has been relied upon (see Acknowledgements).

Habitat assessment

Four environmental variables were used to compare the conditions in which *Acacia pendula* has been recorded within and outside of the Hunter Valley: annual rainfall (30-year average, 1965–2005, from Bureau of Meteorology 2013); geological age (NSW Department of Primary Industries 2006); Australian soil classification type (NSW Office of Environment and Heritage 2013); and elevation (Gallant et al. 2011). Elevation data were in raster format while other datasets were vector format. Rainfall was summarised as 100 mm intervals and elevation as 100 m intervals. These variables are major determinants of plant distribution and were readily available in a consistent format to cover the whole of New South Wales.

Acacia pendula occurrence records from within the Hunter Valley were collated from several sources and as mentioned most had been verified by us through site inspection. Records were sourced more broadly for New South Wales (NSW, excluding the Hunter) from BioNet (http://www.bionet.nsw.gov.au/). All records were cleaned of duplicates and any NSW records with a reported accuracy greater than 1 km were removed. Because there was some tight clustering of records in both data sets, all were overlaid on a 100 m grid and the centroids of all grid cells that contained records were used to represent occurrences. This process reduced data points from 147 to 126 for the Hunter Valley, and 1082 to 646 for NSW records. The values of the four environmental values at each occurrence record were tabulated in a GIS and the data exported for analysis.

A Chi-square test of independence was used to determine whether there was a significant difference between Hunter Valley and NSW records for each environmental value. The null hypothesis was that the two data sets (Hunter & NSW) are independent (i.e. data from one cannot predict the other). To maintain consistency with the assumptions of the Chi-squared test (that <20% of cells have an expected count >5) variables with low counts were grouped into a single variable.

Results

Exploration within the Hunter Valley

Allan Cunningham (1823–1827)

Allan Cunningham, government botanist for the King, had a significant influence in the early development of Australian botany and was influential in the opening up of the Hunter (McMinn 1970a). It was Cunningham himself who first collected *Acacia pendula* from the Lachlan River in central western New South Wales in 1817, a species which was commonly encountered throughout central New South Wales (Oxley 1820; Lee 1925). The tree that Cunningham described near the Lachlan was the grey-green, pendulous form referred to as morpho-type A in the present paper: "*Gathered seeds of* Acacia pendula, *nova sp., a tree 25 feet high, with much the habit and growth of* Salix babylonica, *leaves simple, lanceolate, the whole tree has a gray hue; common on the low flats near the above mentioned lagoon*" [May 4, 1817; in Lee 1925].

Cunningham later undertook three expeditions through the Hunter Valley (Figure 3) during the years 1823–1827 (Lee, 1925; McMinn, 1970a,b). Despite traversing the Hunter Valley floor in the Singleton, Jerry's Plains, Denman, Muswellbrook, Merriwa and Scone districts, Cunningham did not once mention the presence of *Acacia pendula* until he had travelled northwest from Scone over the Liverpool Range and out of the Hunter Valley (Cunningham 1825, 1828, 1832a,b; Lee 1925). Typical of his mention of *Acacia pendula* were these observations from the Liverpool Plains in May 1827: "*On the morning of the 11th May, we quitted our resting place and pursued a course S. of W. for 3 miles, at length passing round the termination of the hills through dry, brushy forest to shape a more direct line to the N.W. The wooded country was level, scarcely over 1,000 ft. above the sea-level, and at length we crossed the track of Mr. Oxley in 1818, the observation at noon, taken in the midst of dense, drooping* Acacia pendula, *giving us lat. 31°00'34" S., which placed our position about a mile north of that gentleman's line of route to the eastward after he had forded Field's River*" [May 11, 1827; in Lee 1925]; and "*After penetrating brushes of the grey-hued* Acacia pendula, *we stretched to the N.W. about four miles over declining country, forest and open plain, with vegetation destroyed by drought...*" [May 11, 1827; in Lee 1925].

After returning to the upper Hunter from the Darling Downs in 1827, Cunningham explored the Goulburn River valley (west from Denman) *en route* to Bathurst (McMinn 1970b). If *Acacia pendula* was present in abundance in any of the areas he explored in the Hunter, it seems likely that Cunningham would have noted it in his diaries. Based on extracts contained in Lee (1925), Cunningham mentions the presence of *Acacia pendula* on at least twenty occasions during his explorations, but not once when in the Hunter Valley.

Thomas Mitchell (1831)

Major Thomas Mitchell undertook three expeditions into the interior of eastern Australia between the years 1831 and 1836 (Mitchell 1838). Accompanying him on his journeys was botanist Richard Cunningham, brother of Allan, who ultimately met his death at the hands of Aborigines near the Bogan River. During his first journey from Sydney, Mitchell passed through Wollombi, Broke, Wambo (near Jerry's Plains), Muswellbrook, Wingen Maid (all within the Hunter; from 26 November to 5 December 1831, and back again in early March 1832) and then over the Liverpool Range onto the Liverpool Plains (Figure 3). Significantly, not once did Mitchell mention the presence of *Acacia pendula* until he

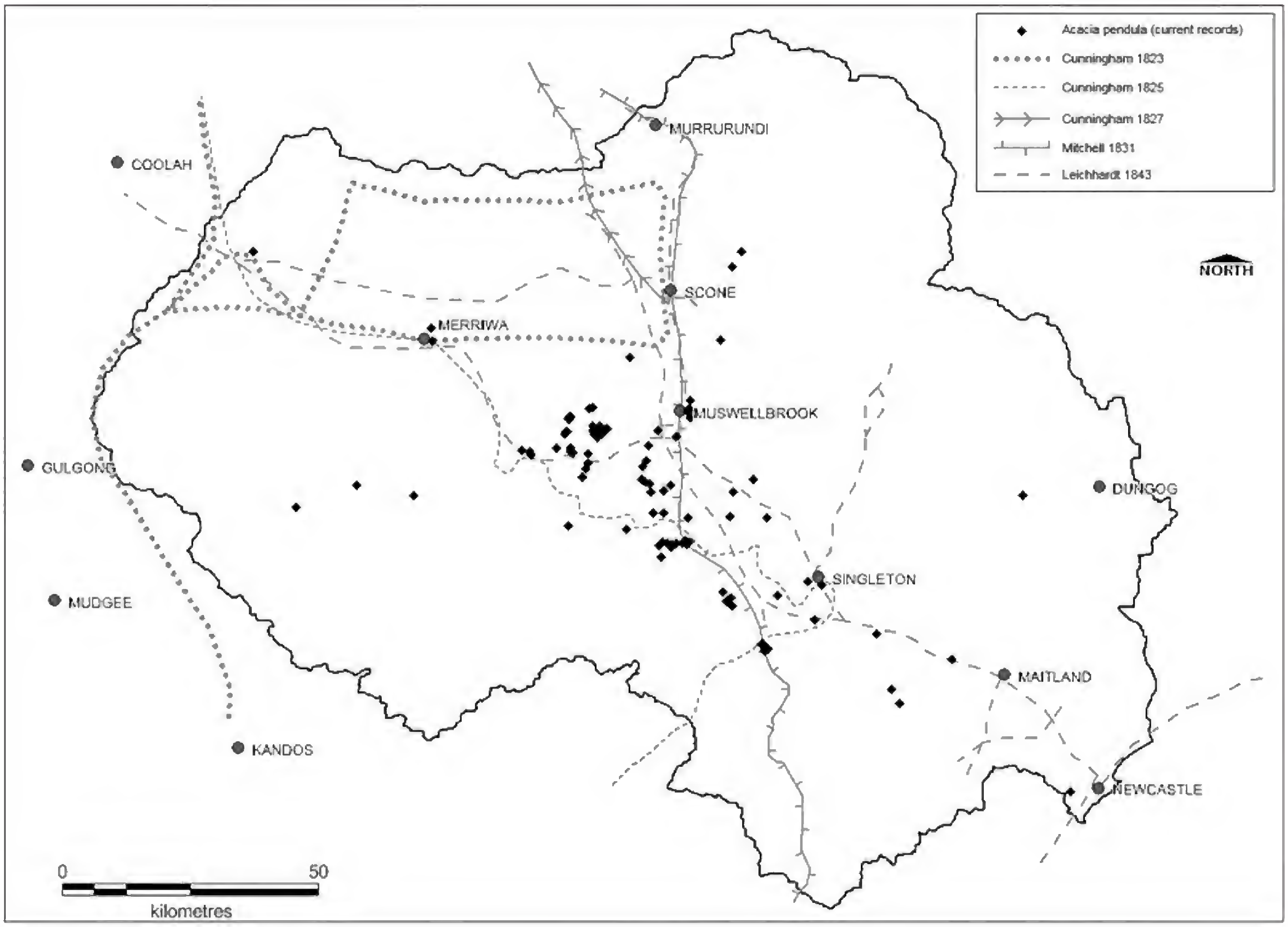

Fig. 3. Approximate main routes of early botanical explorers Allan Cunningham, Thomas Mitchell and Ludwig Leichhardt, together with current-day records of ***Acacia pendula*** (routes taken from Mitchell 1838; Aurousseau 1968; McMinn 1970b; Fallding & Benson 2013).

was near the Peel River, between Gunnedah and Tamworth. At this location, in December 1831, Mitchell wrote (our emphasis): "*On crossing another low ridge beyond this we descended to a valley in which I saw, for the first time, that beautiful shrub of the interior, the* Acacia pendula. *The foliage is of a light green colour and it droops like the weeping willow; the bark is rough, and the trunk seldom exceeds nine inches in diameter. The wood of this graceful tree is sweet-scented, of a rich dark-brown colour, and being very hard, it is in great request with the natives for making their boomerangs and spearheads. It appears to grow chiefly on flats which are occasionally inundated*" [December 14, 1831; Mitchell 1838]. Why would Mitchell refer to "*that beautiful shrub of the interior*" if he had already encountered it in the Hunter Valley?

Acacia pendula is subsequently mentioned on twenty-one occasions throughout western NSW where Mitchell travelled up until 1836, particularly around the Nandewar Range and surrounding districts. He specifically noted its first occurrence since departing Sydney near the Peel River, but not before.

Ludwig Leichhardt (1843)

The German scientist Ludwig Leichhardt travelled through the Hunter *en route* to Moreton Bay between March and June 1843 (Darragh & Fensham 2013; Fallding & Benson 2013). His impressive scientific legacy from all of his travels in Australia has only come to light well after his death, where he is now regarded, like Charles Darwin, as an authentic 'man of science' (Fensham 2013), with a keen eye for scientific detail. From his lodgings at Glendon (near Singleton), Leichhardt passed through the Hunter localities of Ravensworth, Rouchel Brook, Bengalla, Wingen, Dart Brook, Myall Hill, Wybong Creek, Krui River, Cassilis, Coolah and the Liverpool Range onto the Liverpool Plains. Aurousseau (1968) shows a map of Leichhardt's journeys through the Hunter, which are included in the present paper on Figure 3. In his journal, Leichhardt first mentions *Acacia pendula* after leaving Bayly's Station on 25 March 1843: "*Myall woodland, the black trunks and their drooping branches and leaves resemble dark weeping willows, the young saplings and bushes with stiff grey-green leaves*". In his entry of 1 April 1843, he describes the species in some detail, and also outlines other "*plants of the Myall brush*" (Darragh & Fensham 2013). Both of these locations are north of the Liverpool Range and outside of the Hunter Valley. Despite passing through parts of the Hunter where *Acacia pendula* is currently present (Glendon, Singleton, Ravensworth, Muswellbrook, Bengalla, Denman, Wybong Creek, Cassilis), these were not noted by Leichhardt in 1843. Prior to this expedition, it seems Leichhardt was already familiar with *Acacia pendula* from a planted specimen: on 8 April 1843 while on the Liverpool Plains describing the flower heads of *Acacia undulifolia*, he writes that it is "*almost like* Acacia pendula *in the botanical garden*" (presumably the Royal Botanic Gardens in Sydney).

Exploration outside of the Hunter Valley

After its original collection by Allan Cunningham during the 1817 John Oxley-led expedition, *Acacia pendula* was regularly remarked upon by many explorers. Between 1817 and 1862 John Oxley, George Evans, Charles Sturt, Thomas Mitchell, Edward John Eyre, Ludwig Leichhardt and William Landsborough all make reference to *Acacia pendula* in their writings. The frequency of these remarks throughout NSW, Queensland, Victoria and South Australia, contrast with the lack of such comments made by explorers of the Hunter Valley.

John Oxley (1817)

Surveyor-General John Oxley led two expeditions from Bathurst into the interior during 1817 and 1818. In Oxley's journals, observations on the presence of *Acacia pendula* were made on eleven separate occasions, often extolling the virtues of this "beautiful" tree: "*On the plain, the* Acacia pendula *again made a very fine appearance*" [June 26, 1817; Oxley 1820].

George Evans (1818)

Deputy Surveyor-General and explorer George Evans documented his observations on a short journey starting from Mount Harris (300 km north-west of Bathurst) during July 1818 (appended in letter form in Oxley 1820). In this letter, Evans notes the presence of *Acacia pendula* on three occasions. Shortly after leaving Mount Harris, he writes: "*For six miles the country tolerably good; afterwards, to the end of my day's journey, it was alternately* Acacia pendula *scrubs, and cypress brushes; the soil light, and full of holes; abundance of water, but, latterly, no grass*" [July 8, 1818; Oxley 1820].

Charles Sturt (1828–30)

Between 1828 and 1830, Captain Charles Sturt undertook two expeditions into the interior of southern Australia. The first journey was west to the Macquarie River and Sturt noted the presence of *Acacia pendula* initially in the Wellington Valley after leaving Sydney, and then a further eighteen times during this journey: "*As we neared the stream we noticed the* Acacia pendula *for the first time,—an indication of our approach to the marshes* [the Macquarie Marshes]*"* [December, 1828; Sturt 1833].

Sturt's second expedition travelled south-west from Sydney along the Murrumbidgee and Murray Rivers. Along the Murrumbidgee River, he first encountered the species, which was then mentioned a further six times at various points around the region. In December 1829 he wrote: "Acacia pendula *now made its appearance on several plains beyond the river deposits, as well as that salsolaceous class of plants, among which the* schlerolina *and* rhagodia *are so remarkable*" [December 9, 1829; Sturt 1833].

Thomas Mitchell (1831–45)

After leaving the Hunter Valley in 1831, Major Thomas Mitchell continued on his journey northwards, across the Liverpool Plains and onto the Darling Downs. In subsequent years, he explored along the Darling River (1835), the Lachlan River (1836) and the Warrego and Barcoo River systems in central Queensland (1845). As noted earlier, Mitchell made reference to *Acacia pendula* on twenty-one occasions in writings of his first three expeditions. During his fourth expedition, which attempted to locate a route between Sydney and the Gulf of Carpentaria, Mitchell noted *Acacia pendula* on at least thirty occasions. So embedded in his mind was this characteristic species of the interior, that he once again made note of it within a regional context: "*We crossed a deep watercourse falling to the S.E.b.S. [south-east by south], and entered on a noble flat of firm rich soil, whereon grew luxuriantly, the* Acacia pendula *(not previously seen by us in that region), and the two best kinds of grass,* Anthistiria *and* Panicum loevinode*"* [May 26, 1848; Mitchell 1848].

Edward John Eyre (1840)

In 1840, Edward John Eyre led an expedition north from Adelaide in an attempt to reach the centre of Australia. At Mt Hopeless in the Flinders Ranges, the attempt was abandoned. While in the Flinders Ranges, Eyre makes note of the presence of *Acacia pendula* in the area: "*Late in the afternoon we reached a watercourse, which I had previously named Myall Ponds, from the many and beautiful* Acacia pendula *trees that grew upon its banks*" [June 30, 1840; Eyre 1845]. Eyre also notes that *Acacia pendula* was used by the Aboriginals to make Boomerangs for hunting.

Ludwig Leichhardt (1844–45)

After his explorations in New South Wales, Leichhardt undertook a journey of some 3000 miles from Moreton Bay in Queensland, to Port Essington in the Northern Territory during 1844 and 1845. In his writings, Leichhardt often compared his observations on flora and fauna from Queensland to the Hunter Valley, confirming his familiarity with the Hunter. For example, in June 1844, he wrote a direct reference to the small upper Hunter Valley location of Wybong near Denman (and the site of some current day stands of *Acacia pendula*): "*The country was partly rocky; the rock was a coarse conglomerate of broken pieces of quartz....; it greatly resembled the rock of the Wybong hills on the upper Hunter...*" [June 13, 1844; Leichhardt 1847].

Several other references to fauna ("*flying squirrel...of the Hunter*"; "*Jew lizard of the Hunter*"), flora ("*the box with long lanceolate leaves which prefers stiff flats on the tributary creeks of the Hunter*"; "*A species of native tobacco, with smaller blossoms than that of the Hunter...*"; "*A grass, well known at the Hunter by its scent resembling that of crushed ants, was here scentless...*"), and previous acquaintances ("*the kind support I received from R. Dawson, Esq., of Black Creek, Hunter's River...*"; "*...after Helenus Scott, Esq., of Glendon, Hunter's River, who had kindly assisted me in my expedition*") confirms that Leichhardt had a good knowledge of the Hunter Valley region.

Leichhardt passed through the Darling Downs in September 1844 noting: "*Belts of open forest land, principally composed of the Box-tree of the Colonists (a species of* Eucalyptus*), separate the different plains; and patches of scrub, consisting of several species of Acacias, and of a variety of small trees, appear to be the outposts of the extensive scrubs of the interior. There are particularly three species of Acacias, which bestow a peculiar character on these scrubs: the one is the Myall (*A. pendula*)--first seen by Oxley on Liverpool Plains, and afterwards at the Barwan, and which exists in all the western plains between the Barwan and Darling Downs--whose drooping foliage and rich yellow blossoms render it extremely elegant and ornamental*" [September 30, 1844; Leichhardt 1847]. Leichhardt postulated that *Acacia pendula* reached its northern most limits near Mt Lowe in central Queensland, inland from Shoalwater Bay, a fact supported by current day herbarium collections. Of interest also is his reference to the ornamental nature of *Acacia pendula.*

William Landsborough (1862)

William Landsborough led an expedition from Brisbane to the Gulf of Carpentaria in search of survivors from the ill-fated Burke and Wills expedition of 1860. Landsborough, although clearly not educated in botany, was able to distinguish between different types of Acacia, comparing one ("*myall*") to specimens he had seen elsewhere, and referring to them as "*drooping acacia*", now known as Weeping Myall. In December 1861 he wrote: "*At 6.43 made one mile south to a clump of trees resembling myall, which I have seen before to the west of Rockhampton* [presumably the Emerald district]" [December 12, 1861; Landsborough 1862].

Three months later, in March 1862 he noted: "*Towards the river the country is wooded with a kind of myall, but not the drooping* Acacia" [March 15, 1862; Landsborough 1862]. On April 29, 1862, Landsborough made the observation that *Acacia pendula* generally occurs on the better soils, and that their leaves make acceptable fodder for stock: "*The drooping acacia grows on it. I love these trees; their foliage is so beautiful, and the wood when cut has a fine aromatic smell. The grain of the wood is nearly as hard as ebony; besides it is characteristic of the best pastoral country as it only grows on good country. Its leaves are useful and good for stock, which are fond of eating them*" [April 29, 1862; Landsborough 1862].

The journals of these seven explorers testify that *Acacia pendula* was an easily recognisable and noteworthy species to include in appraisals of travels in central eastern Australia (1817–1862). It is mentioned on more than 100 occasions. In stark contrast this species was never mentioned in exploration undertaken by Allan Cunningham, Thomas Mitchell and Ludwig Leichhardt in the Hunter Valley in the 1820s to 1840s.

Database and herbarium records

There are six sheets of *Acacia pendula* at the Kew Herbarium (London), including two collections attributed to Mitchell (K000806166 & K000806167) and two to Cunningham (mounted together but duplicated on K000806169 & K000806170). The K000806166 collection of Mitchell is annotated "*subtropical New Holland*" from 1846, while Cunningham's specimens are noted "*Lachlan River, Cunningham 434, 1817; Hunters River, Cunningham 113, April 1825; Mitchells Expedition 1835, Nammoy* [sic] *River*". The latter collection refers to sheet K000806167, and was not collected by Allan Cunningham (he was at that time back in England), but probably by his brother Richard who accompanied Mitchell as botanist during 1835.

The 1825 *Hunters River* collection attributed to Cunningham (left hand side of K000806169 & K000806170) represents the first from the region. The label on this sheet appears in a different hand to Cunningham's, and was prepared by Robert Heward (his legatee) prior to its donation to Kew in 1862. Viewing the scanned image of this sheet it is apparent that the Hunters River specimen is morphologically quite different to both the Lachlan River and Namoi (Nammoy) River collections, and is in appearance very similar to the plants (morpho-type C) now present in the Hunter Valley (see http://apps.kew.org/herbcat/getImage.do?imageBarcode=K000806169). No details of this collection are noted in Cunningham's journal, which may suggest that its presence was not considered unusual: a curiosity since *Acacia pendula* was commonly mentioned in journals. An alternative view is that Cunningham may have been uncertain of the identity of the specimen he collected at Hunters River, and that it perhaps represented a novel species yet to be determined. In mid-April 1825, when moving through the Denman – Mt Dangar area of the upper Hunter, Cunningham noted the presence of "[Acacia] *sp. new sp. linear leaf*" below sandstone escarpments, potentially referring to this collection. This linear-leaved *Acacia* is most likely *Acacia linearifolia* which grows abundantly in that part of the Hunter (not *Acacia pendula*), and a collection made by Cunningham in 1825 from Mt Dangar is included in the description of that species in Maslin (1994). A further possibility on the origins of the Hunters River specimen is that the label is erroneous and based on assumptions made by Heward well after Cunningham collected the material, but there is no way to determine this conclusively.

Apart from the single Cunningham specimen from 1825, AVH and BioNet data suggests that *Acacia pendula* was next recorded for the Hunter Valley in December 1932 (NSW372937; V.H. Hadley), from a property on the Merriwa Plateau. However notes accompanying this collection at the National Herbarium of NSW document the locality as Borambil, near Quirindi on the Liverpool Plains, well outside the Hunter Valley (by c. 35 km). The positional accuracy of this collection is evidently in error, and it can be discounted as the first record for the Hunter. The next records for the Hunter catchment are from October 1951 at Wybong (NSW372943; L.A.S. Johnson, Muswellbrook-Sandy Hollow Road; shown in Figure 1 as morpho-type B), March 1964 at Warkworth (NSW372929; R. Story, Wambo Estate; shown in Figure 1 as morpho-type C), and June 1997 from the foothills of the Barrington Tops west of Dungog (CBG9710694; B.J. Wallace, East Gresford).

A note on Johnson's 1951 collection states "*Trees 25 feet [7.6 m]. Branchlets drooping*", while the 1964 specimen of Story is accompanied by the note "*Erect, rather straggly tree up to 40 or 50 feet [12.2 or 15.2 m] high, bark fibrous, fissured & grey, suckers very freely from the roots*". Neither of these two descriptions (supported by our observations at these two locations) reflects the graceful form of *Acacia pendula* as previously described by earlier explorers outside of the Hunter and representative of morpho-type A. The erect habit described by Story is consistent with the taxon currently ascribed to many records of *Acacia pendula* in the Hunter (i.e. morpho-type C), which rarely flowers and never produces fruit. A 2007 assessment (Bell 2007) of the *Acacia* present on the former Wambo Estate (the site of Story's collection) showed that all plants there supported the erect habit and freely root-suckering form observed by Story in 1964, and further discussed in Story (1967). Thomas Mitchell on his first journey into the Hunter Valley in 1831, passed through and (presumably) stayed at Wambo Estate, without mentioning the presence of *Acacia pendula*, although admittedly if it was present in its current-day form, Mitchell may not have recognised it as *Acacia pendula*.

The 1997 Wallace specimen (CBG9710694) from west of Dungog is of planted origin despite collection notes advising that it was natural. They state "*Willow like tall shrub to c.4m. Small population on stony hilltop by road. Some root suckering*". Re-location of this collection site by us in 2013 revealed that *Acacia pendula* is naturalising from three planted specimens of morpho-type A either side of a farm gate on the Bingleburra Estate, all within a wider landscape of *Eucalyptus crebra, Eucalyptus moluccana, Eucalyptus glaucina* and *Corymbia maculata*. Bingleburra and the surrounding district of East Gresford were settled early in the 1800s (Jervis 1953a) and it is probable that these three *Acacia pendula* trees were planted as gate markers, and were not an original part of the local landscape. Considerable native vegetation still remains in this region but no further *Acacia pendula* trees have been found in the East Gresford-Dungog locality despite targeted searches. Elements of subtropical rainforest in gullies a mere 5 km to the east are inconsistent with the landscapes normally associated with *Acacia pendula* elsewhere in its range.

Somewhat surprisingly, between 2000 and 2012 over 75 separate location records and specimens of *Acacia pendula* have been lodged for the Hunter Valley, representing a 37-fold increase in the total records since the first collection in 1951. Many records lodged over the past decade are in response to listing of *Acacia pendula* as an endangered population in the Hunter in 2005. Reductions in stock grazing pressure and the re-emergence of browsed *Acacia* from rootstock may also have contributed to the increased

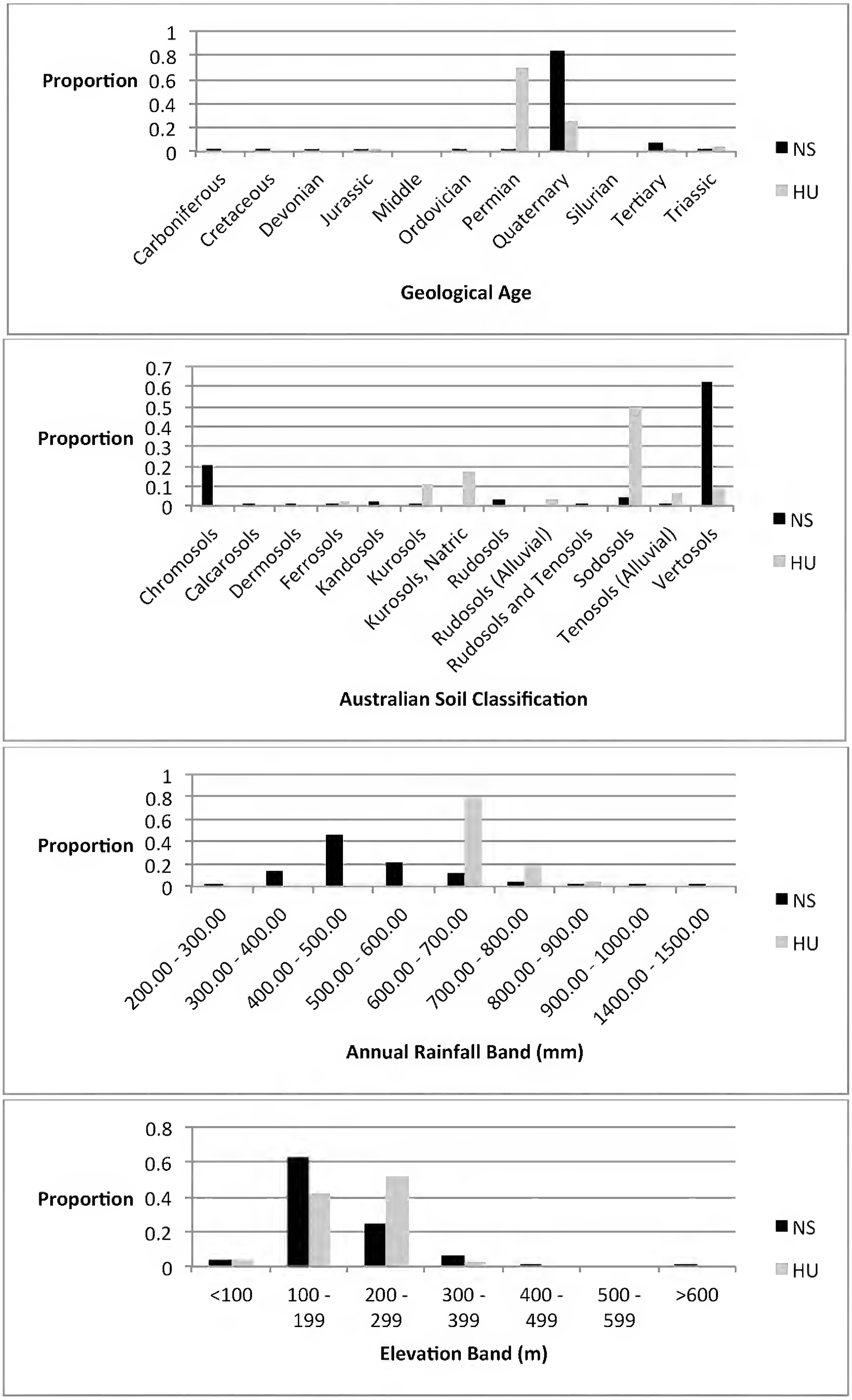

Fig. 4. Environmental analysis of geological age, soil type, rainfall and elevation of Hunter Valley (HU) records (n=126) and New South Wales (NS) records (n=646) of *Acacia pendula*.

records over the last decade. The three morpho-types are clearly recognisable in all of these records, based either on our observations at each site, or as reported by others. Importantly, we postulate that all records for morpho-type A (the 'typical' form) are of planted stock; morpho-types B and C are probably introduced and should perhaps not be attributed to *Acacia pendula* (see later).

Habitat for Acacia pendula

The first collection of *Acacia pendula* by Allan Cunningham in 1817 from the Lachlan River recognised the association of this species with alluvial flats: "*common on the low flats near the above mentioned lagoon*" [May 4, 1817; in Lee 1925]. Thomas Mitchell later remarked (our emphasis): "*At two miles onward from the camp of May 14 we saw bushes of* Acacia pendula *for the first time since we had previously passed that place. The locality of that beautiful shrub is very peculiar, being always near but never within, the limits of inundations. Never far from hills yet never upon them*" (Mitchell 1838). And again in 1848: "*It* [Acacia pendula] *is found only in clay soils, on the borders of plains, which are occasionally so saturated with water as to be quite impassable; never on higher ground nor on any lower than that limited sort of locality, in the neighbourhood of rivers which at some seasons overflow*" [December 18, 1845; Mitchell 1848]. Even those not trained in botany recognised the favoured habitat of *Acacia pendula*: "*The drooping acacia grows on it..... besides it is characteristic of the best pastoral country as it only grows on good country*" [April 29, 1862; Landsborough 1862].

Since then the link between *Acacia pendula* distribution and environmental traits has become well established; most current-day texts agree on the favoured habitat for *Acacia pendula* throughout its geographical range; Tame (1992), for example, describes its occurrence as being "*usually on the heavy loams of floodplains*". In the *Flora of Australia*, Cowan (2001) notes that it "*grows mainly on floodplains on fertile alluvial clay*", while Keith (2004) mentions "*grey clay soils on flats and shallow depressions… far from the active channels*" for his vegetation class dominated by *Acacia pendula.* Boland et al. (2006) states that *Acacia pendula* grows on depositional landforms (plains, seasonal drainage lines & lower slopes of undulating terrain), on heavy textured clay subsoil, while Cunningham et al. (2011) describe habitat as major river floodplains and particularly on heavy clay soils. Research papers describing communities where *Acacia pendula* is characteristic also refer to habitats of alluvial clay soils (e.g. Benson et al. 2010).

There is also a climatic element to preferred habitat. *Acacia pendula* is a species of inland Australia where conditions are harsh and rainfall is low and erratic. In their overview of *Acacia*-dominated vegetation in Australia, Johnson and Burrows (1994) indicated that woodlands where *Acacia pendula* occurs occupy the annual rainfall band of 375 to 550 mm/year, with Queensland populations tending to be at the wetter end of this spectrum. Similarly, Keith (2004) restricts his Riverine Plain Woodlands, dominated by *Acacia pendula,* to the 375–500 mm/yr rainfall band. The Hunter Valley receives considerably more rainfall than this, with figures ranging from 611 mm/year at Scone, to 716 mm/year at Cessnock (Bureau of Meteorology 2013).

Comparison of environmental features of NSW and Hunter Valley populations

Comparison of *Acacia pendula* records from the Hunter Valley with those from elsewhere in NSW showed significant differences between the environmental features across these two regions. Figure 4 shows frequency distribution histograms for each environmental variable tested. The Chi-square test of independence showed that these differences were all significant ($p<0.001$). For the Hunter Valley, the majority of records for *Acacia pendula* lie on Permian sediments, in Sodosol or Kurosol soils, at elevations of 200–299 m, and within the 600–800 mm/yr rainfall band. For other parts of NSW, most records lie on Quaternary sediments, in Vertosol or Chromosol soils, at 100–199 m elevation, and within the 300–600 mm/yr rainfall band.

Discussion

Despite listing of Hunter Valley populations of *Acacia pendula* in threatened species legislation, there is some doubt regarding the presence of this species within the region prior to European settlement. This paper raises important questions concerning the presence of this species in the region, questions that have significant implications on the conservation of this species in the Hunter Valley, and point to the need for urgent genetic assessments of the *Acacia pendula* complex.

Did Acacia pendula occur naturally in the Hunter?

Based on the evidence from historical writings, database and herbarium records, and habitat characteristics, it seems unlikely that *Acacia pendula* ever occurred naturally within this region. There are no collections or records of *Acacia pendula* held in databases or herbaria (except for the 1825 collection of Cunningham which may be erroneous) for the first 128 years of botanical exploration (1823–1951). Two putative records from 1951 and 1964, at Wybong and Wambo respectively, potentially represent the first Hunter records, but these were collected in well-established grazing lands when settlement of the upper Hunter was virtually complete (Perry 1955; O'Rourke 2009). Allan Cunningham (between 1823 and 1827), Thomas Mitchell (1831) and Ludwig Leichhardt (1843), all early pioneering Australian botanists and explorers familiar with *Acacia pendula*, had travelled through the Hunter Valley, including the Wybong and Wambo districts, but none of them made reference to the species. The plethora of *Acacia pendula* records between 2000 and 2012, in areas previously well explored botanically, raise the issue of how a long-lived, resilient and attractive tree, growing widespread across suitable habitat elsewhere, remained effectively unobserved and uncollected for 180 years.

Similarly, the historical record as presented in this paper strongly suggests that *Acacia pendula* was not present during the European expansion into the Hunter Valley in the early

1800s. More contemporary studies are also revealing. Cameron (1935), for example, notes in her regional assessment of NSW vegetation that, "*The region of the Upper Hunter, as before mentioned (p. 24), is most interesting, for several distinctly western species are recorded for that area, of which the following are of importance:* Acacia homalophylla *(Yarran),* Acacia harpophylla *(Brigalow),* Acacia salicina *(Cooba),* Geijera parviflora *(Wilga),* Casuarina luehmanni *(Bull Oak),* Heterodendron oleaefolium *(Rosewood),* Pittosporum phillyraeoides *(Butter Bush) and* Eucalyptus camaldulensis *(Murray Red Gum)*." Notable by its absence is *Acacia pendula*, which if present in the Hunter during the 1930s would surely be mentioned in this context. Continuing, Cameron (1935) states that the western boundary of her region 2c (which lies well west of Mudgee, and beyond the Hunter) "*marks the beginning of the transition region (3), where flourish such trees as* Acacia homalophylla, Acacia pendula, Geijera parviflora, Heterodendron oleaefolium *and* Eucalyptus populifolia". Later assessments of NSW vegetation, most notably that of Keith (2004) and the NSW Vegetation Classification and Assessment (NSWVCA: Benson 2006), recognise four units dominated by *Acacia pendula.* Only Benson et al. (2010) defines a community for the Hunter, the Weeping Myall – Coobah – Scrub Wilga Shrubland of the Hunter Valley, centered on the cemetery at Jerrys Plains.

In the first regional vegetation assessment of the Hunter Valley, Story (1963a,b) discussed twelve major vegetation types, but none of these contain *Acacia pendula.* His discussions on savannah woodlands of box gum and ironbark make no mention of any *Acacia* tree species characterising them, although other small tree and shrub genera are noted (e.g. *Allocasuarina*, *Brachychiton, Bursaria, Callitris, Canthium, Daviesia, Exocarpos, Santalum, Notelaea*). For part of his Rouse savannah land system, a community dominated by the small tree *Acacia doratoxylon* is noted, but few other *Acacia*–dominated examples are evident. The total list of *Acacia* species recorded by Story (1963b) includes twenty-four taxa, including ten tree species, but no *Acacia pendula* (*A. crassa, A. dealbata, A. deanei, A. doratoxylon, A. irrorata, A. melanoxylon, A. parvipinnula, A. prominens, A. salicina, A. schinoides*). It is not until later when examining soil-water relations in partly cleared woodlands that he discusses *Acacia pendula* on the Wambo Estate near Warkworth (Story 1967). Given that the Warkworth area was one of the first districts in the Hunter settled and cleared by Europeans in the early 1800s (Lucas 2013), there is little evidence to suggest that by 1967 the Acacias examined by Story were naturally occurring. Tame's (1984) classification of the Hunter Valley vegetation makes no mention of *Acacia pendula*.

Over recent years, considerable effort has been expended on understanding the regional patterns in native vegetation within the Hunter Valley (e.g. NSWNPWS 1999, 2000; Peake 2006; Sommerville 2010; Sivertson et al. 2012). These projects have used numerical analysis of systematic sample data to delineate and map vegetation communities, and to illustrate trends in the distribution of plant species. Based on these studies, the Hunter Valley floor comprises vegetation systems dominated by Spotted Gum (*Corymbia maculata*), Ironbark (*Eucalyptus fibrosa, E. crebra*), Redgum (*Eucalyptus tereticornis, E. blakelyi, E. camaldulensis*) and Box (*Eucalyptus moluccana, E. albens, E. dawsonii, E. melliodora*). Alluvial soils support Redgum, Rough-barked Apple (*Angophora floribunda*) and Oaks (*Casuarina cunninghamiana, C. glauca*). Alluvial plains and flats characterised by *Acacia* species, such as occurs inland of the Great Dividing Range, are not present in the catchment. It is incongruous that early explorers of the Hunter would have travelled through mile after mile of the ubiquitous ironbark, spotted gum, redgum, apple and box, and not made comment on the contrasting presence of *Acacia pendula* if it were there.

Early explorer accounts also lend support to the vegetation systems currently observed in the Hunter, highlighting regional differences within and outside of the catchment. Aurousseau (1968, in Benson & Redpath 1997), for example, quotes Ludwig Leichhardt: "*Between the Peel and Namoi the forest changes, and instead of riding between spotted gums, box and narrow-leaved ironbark you enter a forest of silver-leaved ironbark whose leaves are greenish grey …*". As noted above, this combination of eucalypts is typical of much of the Hunter Valley floor, and a check of the distribution of these species on Australia's Virtual Herbarium, particularly spotted gum (*Corymbia maculata*) and narrow-leaved ironbark (*Eucalyptus crebra*), suggests that perhaps Leichhardt was actually referring to his exit from the Hunter for the observed change. Further, Leichhardt writes: "*Just as the brigalow gives character to this part of the country* [south-west of Brisbane] *another species of* Acacia*, the myall (*Acacia pendula*) characterises the Liverpool plains and the plains of the Gwydir and the Big River …*". Leichhardt did not include the Hunter in this comparison, despite his familiarity with the region.

The alluvial plains of the Hunter and Goulburn valleys, where it may be expected *Acacia pendula* would occur, have long supported other vegetation types, as evidenced in the writings of Dumaresq (1827) for the Muswellbrook area (our emphasis): "*We tethered our horses in the heat of the day; and, after lighting a fire and making tea for the last time, took a siesta for a couple of hours by the side of the creek, under the shade of a large apple-tree, which is* *the most common tree met with in these parts*. *It is not the apple-tree of Europe, but the Angophora* [Angophora floribunda] *of Linnaeus, and it is a certain indication of a fruitful soil.*"). Cunningham also frequently spoke of Apple-trees and Apple-tree flats in his writings. Today, *Angophora floribunda* is a common remnant tree of creeklines and lower slopes in the Hunter, where it has not been overly cleared for grazing.

Do ecological traits of Acacia pendula concur with Hunter stands?

Most reference texts agree that a pendulous habit is typical for *Acacia pendula,* and is a characteristic commonly used in identification. However, for *Acacia melvillei* and *Acacia homalophylla* (and many other arid-zone Acacias), the pendulous tendency is also a feature to varying degrees. Boland et al. (2006), for example, state that "*Yarran [*A. homalophylla*] is less pendulous than Myall [*A. pendula*] and has a strong propensity to form clonal clumps via root* *suckering*". The root-suckering habit is not often noted in other texts, but virtually all of the non-pendulous forms of *Acacia* within the Hunter show vigorous root suckering. That young plants of *Acacia pendula* are not pendulous, but acquire a pendulous habit when approximately 2 m high has been reported by Umwelt (2006a). Leichhardt noted this trait as early as 1843: "*the young saplings and bushes with stiff grey-green leaves*".

Based on limited field observations, Maslin and McDonald (2004) stated that some *Acacia* species which have the ability to root sucker do so more readily when they grow in areas marginal to their preferred habitat, or when adverse environmental factors prevail (e.g. severe insect predation, severe frost, prolonged drought, fire, etc). Some species, *Acacia saligna* for example, apparently rarely root sucker in cultivated stands but in nature sucker regrowth is common. However, there may be other processes involved. The superficially similar *Acacia aneura* (Mulga) is a very complex group, and has been the subject of intense study in recent years (Miller et. al., 2002; Page et al. 2011). Apomixis (replacement of sexual reproduction by asexual reproduction, such that genetic identities of progeny are identical to the parent) and neotony (retention of juvenile features in the adult phase), as described by Miller et al. (2002), may also be impacting on *Acacia pendula* in the Hunter and exacerbating identification problems.

Many stands of *Acacia pendula* in the Hunter occur in areas depauperate in understorey and ground layer vegetation, a feature not evident in stands further west (e.g. Porteners 1993). Allelopathy (the inhibition of germination and growth of other plants through the release of chemicals into the environment) may be acting in these cases; this will influence the diagnosis and recognition of a community characterised by *Acacia pendula* (such as those Hunter Valley communities currently listed under legislation). Typically, the more hardy and adaptable species are likely to overcome such localised changes to the environment, while others will succumb. Most chemical compounds released by plants are secondary substances produced as a by-product of primary metabolic processes, some beneficial to other plants and some harmful (Lorenzo et al. 2010). While *Acacia pendula* is not yet reported to be allelopathic, many other *Acacia* species are (e.g. Hameed et al 2011; Lorenzo et al. 2012).

Root competition may also be an explanation in those situations where ground vegetation is sparse, and critical resources such as water availability is limited. For example, Harris et al. (2003) investigated the inhibitory effects of White Cypress Pine (*Callitris glaucophylla*) on the growth of ground layer vegetation in south-eastern Queensland. They suggested that, rather than pine litter inhibiting germination and growth of ground cover species, high root competition in dry environments may be responsible. Similar results were reported in *Allocasuarina luehmannii* in semi-arid regions by Morgan et al. (2013). For *Acacia pendula*, Story (1967) discussed the impacts of root competition on the growth of pasture grasses around this species in the Hunter Valley, and concluded that root competition was the most likely cause of bare areas under canopies.

Was Acacia pendula planted for aesthetic purposes or stock-browse?

Given the lack of historical references to *Acacia pendula* in the Hunter, it is reasonable to assume that many of the plants now present originate from plantings, much like those occurring in the Bathurst district (http://plantnet.rbgsyd.nsw.gov.au/floraonline.htm). This is particularly the case for specimens of morpho-type A, which is a commonly used horticultural subject. NSW State Forests long maintained a plant nursery at Muswellbrook in the upper Hunter Valley, which stocked and sold this species for several decades. An advertisement in the *Singleton Argus* of 4 August 1947 recommends the planting of *Acacia pendula* in the Hunter district, following the advice of the Forestry Commission of NSW (Anon 1947). Because of the attractive weeping foliage of this tree (Boland et al. 2006) it has been commonly used throughout the region in avenue and screen plantings. Within the Hunter Valley, good examples occur along the Golden Highway on the eastern approach to Merriwa, along the New England Highway at Ravensworth, Denman Road between Denman and Muswellbrook, within salinity trials at Wybong, along Range Road in the Singleton Army Training Area and at Cessnock airport. In Victoria, *Acacia pendula* is reported to have originally been naturally rare (Keith 2004; McDougall 2008), but plantings as long as 100 years ago have clouded knowledge of natural stands (Venn 2004) and genetic studies are required for clarification. Interestingly, records of the similar arid-zone species *Acacia aneura* from the upper Hunter Valley, although included in distributional information, are suspected by the National Herbarium of NSW to have been introduced (http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=sp&name=Acacia~aneura).

Plantings of various species have a long history in the Hunter. Breton (1833), for example, during his journey through the region made reference to a land owner in the Muswellbrook district and his penchant for planting various trees and shrubs, suggesting that as early as the 1830s some settlers were already introducing non-endemic and exotic species to the region: "*Twelve miles farther is St Hiliers, one of the finest estates on the Hunter; the house is the best in the district; and as the proprietor is constantly engaged in planting the most useful and ornamental trees (one of the very few instances I have seen in the 'bush'), the place bids fair to remind him, at no very distant period, of an English country house with its shrubberies*". And indeed, Breton (1833) actively encouraged further planting of trees (both native and of European extraction) to potential new settlers: "*I cannot but think the colonists might more generally introduce the various European trees upon their farms … Even by encouraging clumps of acacias, the appearance of the country would be improved …*". During the late nineteenth century, Joseph Maiden contributed greatly to the movement of *Acacia* specimens and knowledge throughout the colonies and the World, including the recommendation of certain species for planting within New South Wales (Frawley 2010).

Jerrys Plains cemetery is a key location mentioned specifically in NSW and Commonwealth threatened species legislation, but it is likely that *Acacia pendula* stands there originate from earlier plantings or escapees. No mention of the species was made by Allan Cunningham, Thomas

Mitchell or Ludwig Leichhardt, all of whom were familiar with the species and moved through the area between 1826 and 1843. Potential habitat for *Acacia pendula* in Jerrys Plains would most likely be those flats in proximity to the Hunter River, about which a visitor to Jerrys Plains in 1827 remarked: "*a particularly rich and beautiful strip of narrow land, formed by the alluvium of the river, and the debris of the mountains. This little tract extends westward about ten miles along the river, and astonishing to say, is comparatively unknown by the settlers, either new or old.*" (cited in Jervis 1953a, p. 105). However, the cemetery site is located well upslope from these alluviums, on a gently sloping hillside of Permian clays, and it would seem unlikely to have once naturally supported *Acacia pendula*.

During preparation of a management plan for the Jerrys Plains cemetery site, Umwelt (2006b) reviewed historical aerial photographs and found that most woody vegetation had been cleared in 1954 and again in 1958, so that current day vegetation represents about 50 years of regeneration. It is likely that clearing of vegetation has occurred intermittently since at least 1890 (the time of first burials), and quite possibly earlier than that. A notice in the Singleton Argus newspaper of 30 October 1895 pertains to the clearing of the cemetery to which it was "*put into something like decent appearance*" (Anon 1895). Current-day stands of *Acacia pendula* consequently lie at a location that has been regularly cleared and managed for at least 120 years, and raise further doubts over the origin of the plants growing there.

For the more unattractive morpho-types B and C, evidence for plantings of *Acacia pendula* as stock-browse specimens is perhaps more informative. Pastoralists soon recognised the browse potential of *Acacia pendula*, as evidenced in the writings of Ludwig Leichhardt, Thomas Mitchell and William Landsborough during the mid 1800s. In his many observations on the behaviour and habits of cattle, Leichhardt noted on 16 May 1843 that "*In the myal forest grows a shrub that the cows eat with great appetite, although they can live off the myal*". Mitchell (1848) writes: "*The* Acacia pendula*, a tree whose habitat is limited and remarkable, is much relished by the cattle. .... In such situations, even where grass seems very scarce, cattle get fat; and it is a practice of stockmen to cut down the* Acacia pendula *(or Myall trees, as they call them) for the cattle to feed on*". Later, Landsborough (1862) observed that: "*Its leaves are useful and good for stock, which are fond of eating them*". Such observations are supported by more contemporary writings, extolling the nutritional value of *Acacia* phyllodes and pods as stock-browse (e.g. Dynes & Schlink 2002). Indeed, Butler (2007) noted that *Acacia pendula*, along with several other arid-zone species within Brigalow (*Acacia harpophylla*) vegetation communities, are readily eaten by domestic stock and native or feral herbivores. Much like Kurrajong (*Brachychiton populneus*) in other areas, lopped trees were often used as forage during drought periods (Froggatt 1923; Goodchild & McMeniman 1987; Cunningham et al. 2011).

An alternative explanation relating to the presence of morpho-types B and C may be the misidentification of stock-browse. For example, in the initial inspections of *Acacia* for an Environmental Impact Statement at the Wambo mine at Warkworth (the former Wambo Estate established by James Hale in 1824), plants were identified initially as *Acacia aneura* but are now referrable to *Acacia pendula.* (recounted in Bell 2006, and in keeping with the identification of these trees advanced by Story 1967) Given many authors (e.g. Fox 1987; Boland et al. 2006) note *Acacia aneura* (Mulga) as being the most important fodder tree in Australia, it is quite plausible that early pastoralists mistakenly collected seed or cuttings of an *Acacia* species from inland areas, thinking it was *Acacia aneura,* to establish fodder trees on their holdings for future drought relief. Indeed, the photograph of *Acacia aneura* in Boland et al. (2006, p. 135) bears a strong resemblance to Hunter Valley plants currently referable to morpho-type C.

Was Acacia pendula accidentally introduced?

During the 1820s to 1840s, land grants in the Hunter Valley were made to wealthy pastoralists, who were seeking respite from drought-affected grazing lands in the Hawkesbury and Sydney districts. From the Hunter, further exploration onto the Liverpool Plains was made by these pastoralists (generally following the route taken by Mitchell in 1831: see Figure 2), where new grazing properties were established (Ellis no date), often without the sanction of Government. In 1827, James Robertson (Plashett estate, Jerry's Plains) was one of the first men to drive sheep and cattle across the ranges onto the Liverpool Plains, locating and establishing properties at Mooki Springs and along the Namoi River (Hunter 2010). He would later bring stock back to the Hunter for fattening and marketing. Similarly, David Brown and family relocated to Jerry's Plains from Cattai (north-western Sydney) in the early 1830s, to be more central for their push to the north-west and the Liverpool Plains (Griffiths 2012). During the 1830s, the Brown family drove fattened cattle from the Gwydir/ Namoi Rivers area, south through what are now the townships of Narrabri, Turrawan, Boggabri, Gunnedah, Murrurundi, Scone and Muswellbrook to Jerrys Plains. Jerrys Plains was used as a staging point for sending cattle to the Maitland or Newcastle markets, or along the Bulga track to Windsor (Griffiths 2012). James Hale (Wambo Estate, Jerrys Plains) and George Bowman (Arrowfield, Jerrys Plains) also undertook cattle runs from the Hunter to the Gwydir, where they too established grazing properties (Lucas 2013). In 1866, an entry in Bailliere's Gazetteer stated of Jerry's Plains: "*The town is so situated that all the fat stock from Queensland and the Bogan pass through it*" (in Ellis no date).

Periods of drought were influential in drives such as these to search further afield for grazing lands. Griffiths (2012) cites an article from the press of August 8, 1846: "*..the cattle still suffer greatly from want of water, there being none anywhere, but in the river, within miles of which there is not a blade to be seen*". During this time, cattle were fed the leaves of "*the oaks growing by the side of the river*", presumably River Oak (*Casuarina cunninghamiana*). Popinjay (1990), recounting articles to The Australian newspaper from October 1827 concerning Jerry's Plains, writes that the area was "*…generally abounding in rich grass, but now, after a* *six months' drought (August) and depasturing two or three thousand head of cattle, it is for the most part brown and bare, and partakes more of the character of an extensive stock-yard, than a district justly celebrated for its rich and abundant pasture*". Such comments are later supported by Breton (1833): "… *during the 'great drought' (1826, 27, 28, 29) not a blade of grass was visible, except in shady spots* ...". Alternative grazing lands outside of the Hunter were therefore seen as a necessity to circumvent the perils of drought years. In many cases, holdings on the Liverpool Plains were extensive, such as the 300,000 acres owned by Samuel Clift in the 1840s, easily eclipsing his 5,000 acres in the Hunter during the preceding decade (Ellis no date).

Given the widespread current-day occurrence of morpho-types B and C in agricultural lands in the Hunter, it is perhaps more plausible that these plants were introduced accidentally through stock movements such as between the Hunter and Liverpool Plains. A number of *Acacia* species are known to be consumed by large herbivorous mammals, and when seeds and pods are ingested there is potential for long-distance dispersals to occur (Razanamandranto et al. 2004). This process, endozoochory, allows for the acidic conditions and enzymes present in the rumen and large intestine of mammals to scarify the seed surface, such that seed germination is possible after the deposition of faeces in favourable environments (Haameyer et al. 2010). In their study on Argentinean *Acacia* species, Venier et al. (2012) concluded that the structure of the seed coat in hard seeded species is crucial to the success of endozoochory, supporting the results of earlier studies on other legumes (e.g. Gardener et al. 1993; Danthu et al. 1996; Shayo & Uden 1998). Commonly, when *Acacia* pods and seeds are eaten by cattle, seeds pass through the digestive tract unharmed as they are protected to some extent by pod structure (Miller & Coe 1993).

During the early days of settlement in the Hunter Valley, fencing was limited to areas immediately around homesteads, allowing stock to roam freely (Ellis no date) across wide areas, tended by shepherds. As early as 1829, there were reportedly 119,391 head of sheep, 46,805 head of cattle and 1,316 horses in the region (Jervis 1953a). It is not unreasonable to assume, therefore, that once *Acacia* species had been introduced into the region, their dispersal via livestock across the valley was relatively unregulated. In one study of the introduced *Acacia nilotica* in the Northern Territory, Radford et al. (2001) describe the paddock-scale dispersal of this species by cattle, which readily consume and spread viable seed through their faeces. Paynter et al. (2003) reported that the seed of this species take 6 days to move through the gut of cattle, and that 40% of seed passed in this way were viable. In the Sudan, Razanamandranto et al. (2004) postulated that the 15–30 km daily movement by livestock could play a major role in the long-distance dispersal of *Acacia* species there. It is more than feasible that consumption of seeds of *Acacia pendula* and other arid-zone Acacias by cattle, followed by 6 days of travel (either from the Liverpool Plains to the Hunter, or within the Hunter Valley itself), could result in the introduction and spread of viable *Acacia* seed to the region. During the 1870s, cattle were permitted by licence to travel no more than 10 miles (16 km) per day along designated travelling stock reserves (Smiles et al. 2011), meaning that nearly 100 km could be traversed before *Acacia* seeds were deposited in cattle dung. Prior to 1870, daily distances travelled may well have been longer.

Is Acacia pendula naturalising in the Hunter?

During investigations undertaken for this paper, it has been observed that some planted specimens of *Acacia pendula* in the Hunter (morpho-type A) are showing signs of naturalisation, particularly in those situations where ground disturbance has occurred. Good recruitment and/ or root suckering has occurred at the Bingleburra (East Gresford) population (Figure 5), the Singleton Army Training Area and at a disused farm near Muswellbrook. These populations are characterised by a few taller, older trees amongst younger plants, and have all flowered and fruited shedding seed into the immediate locality. Ground disturbance, such as the grading of road edges by machinery or lawn mowing, has promoted seed germination. At the Muswellbrook site, an original row of eight specimens (now ~12 m in height) planted near an old homestead have seeded abundantly and created a stand approximately 40 x 90 m in size (Figure 6). Previous earthworks evident within the original stand of trees have likely promoted germination of the seed bank. The passage of fire through any of these stands supporting planted specimens of *Acacia pendula* would presumably promote mass seedling emergence.

Acacia pendula has not previously been reported naturalising in regions outside of its accepted distributional range, although VICDSE (2009) includes the species in the low risk category of their environmental weed list for the Inland Plains bioregion (a curiosity, since this species is also listed as threatened in Victoria). However, a number of other *Acacia* species have done so, most notably *Acacia baileyana, A. cyclops, A. dealbata, A. decurrens, A. longifolia, A. pycnantha, A. saligna* and *A. sophorae* (Costello et al. 2000; Morgan et al. 2002; Emms et al. 2005; Eichhorn et al. 2011; Millar & Byrne 2012). In his review of introduced plants in Australia and their weed status, Randall (2007) includes forty-three native Australian *Acacia* species which have naturalised beyond their accepted geographical ranges. Within New South Wales, recent papers by Hosking et al. (2003; 2007; 2011) have included only *Acacia pulchella* var. *pulchella* as showing evidence of recent naturalisation. Over time, naturalisation of native Australian species outside of their original distributions can present complexities for management and conservation planning, particularly when those species are threatened taxa (cf. Rocha & Bergallo 2012). Given the propensity for ornamental planting of *Acacia pendula*, it is surprising that naturalised populations have not been reported previously.

The seed of *Acacia pendula* is evidently hard, and requires some form of pre-treatment to induce germination. Ghassali et al. (2012) evaluated four stratification techniques (water, boiling water, sulphuric acid, mechanical scarification) on the seed of 14 species of *Acacia*, and found that mechanical scarification produced the highest germination rate in *Acacia pendula*. This finding is supported by that of Cromer (2007), who found that treatment of seed by boiling water resulted in only 15% germination success. Based on the germination studies of Larsen (1964) and Aveyard (1968) for *Acacia pendula*, Auld (1986) indicated that scarification produced the highest germination rates (>80%), followed by boiling water treatment (<70%), the addition of acid (<70%), application of dry heat (~40%), or with no seed treatment (~30%). This would suggest that, for example, any grading of roadside populations of *Acacia pendula* will likely result in fresh germination from the seed bank. Conversely, seed falling in a grassy paddock is unlikely to result in mass germination without scarification. Interestingly, Froggat (1923) in discussing the Bag Shelter Moth (*Teara contraria*), suggested ready germination of *Acacia pendula* where it is protected from grazing stock: "*Wherever land is enclosed and protected from stock, these* acacia *seedlings spring up in such numbers as to form regular thickets, and the homestead and horse paddocks are usually ornamented with groups of these trees on all the western stations*". It is likely that the seedlings that Froggat refers to here are actually resprouts from root suckers, appearing after the removal of grazing stock, rather than freshly germinated seed. Such an assumption commonly occurs today for stands of *Acacia pendula* that have had grazing pressures removed (e.g. Bulga Coal Management Pty Ltd 2013).

Could there be an undescribed new Acacia species in the Hunter?

The available evidence suggests strongly that *Acacia pendula* (morpho-type A) has never existed naturally in the Hunter Valley. If this is the case, then what becomes of the many small stands of trees and shrubs currently attributed to this species (morpho-types B & C) that have surfaced in the region since 2000? There is a slim possibility that these represent an as yet undescribed new species of *Acacia* worthy of protection, but this is difficult to confirm when flowering is typically aborted prior to fruiting. All records occur in heavily grazed lands and none are within intact natural bushland, so it would appear more likely that the plants have been introduced and the unfavourable habitat is manifesting itself in vigorous root suckering, neotony and apomixis. Nevertheless, the similarly clonal *Acacia atrox* from the North Western Slopes of NSW has likewise not been recorded in fruit (Kodela 2001; Copeland & Kodela 2012), but is currently treated as a distinct species and listed as a threatened species. Genetic studies will be necessary to resolve this issue satisfactorily, but at present it is clear that these Hunter Valley plants are not *Acacia pendula*. Until resolution has been achieved, there may be precautionary merit in retaining some level of conservation significance over morpho-types B & C.

What are the conservation implications of the absence of evidence for natural stands of Acacia pendula in the Hunter?

These primarily reflect the current listing of the species in various threatened species legislations, the protection such listings impose on the species, and the provision of restoration funding that these listings currently attracts. Within the Hunter Valley, *Acacia pendula* is protected as an Endangered Population (NSW TSC Act) and is a characteristic component of a vegetation community listed in New South Wales (the *Hunter Valley Weeping Myall Woodland*) (NSW TSC Act) and Commonwealth legislation (the *Weeping Myall-Coobah-Scrub Wilga Shrubland of the Hunter Valley*)(EPBC Act). Elsewhere in New South Wales, *Acacia pendula* is also included in an Endangered Ecological Community, *Myall Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain, Murray-Darling Depression, Riverina and NSW South Western Slopes Bioregions* (NSW TSC Act). This community cannot apply fully to stands of *Acacia pendula* in the Hunter catchment as it is mostly outside the Darling Riverine Plains, Cobar Peneplain, Murray-Darling Depression, Riverina and NSW South Western Slopes Bioregions; that portion of the catchment within the Brigalow Belt South bioregion comprises the Tertiary basalts of the Merriwa Plateau, where very few records exist.

Over recent years, fines for the removal of purported individuals of *Acacia pendula* in the Hunter have been imposed through the NSW Land and Environment Court (e.g. Plath v Hunter Valley Property Management Pty Limited [2010] NSWLEC 264), and have been reported in the media (e.g. McCarthy 2011; Ryan 2011). Additionally, approval conditions for a number of coal mines in the Hunter Valley have requirements for the re-establishment and protection of *Acacia pendula* to compensate for the removal of this species from mine paths. Typical of these are that "*the proponent shall ensure that the offset strategy and/or rehabilitation strategy is focused on the re-establishment of.... Weeping Myall (*Acacia pendula*)...*" from the Mt Arthur consolidation approval in 2010 (BHP Billiton 2010), and "*the establishment of a Weeping Myall Management Area within the Project area to promote the recovery of the Weeping Myall (*Acacia pendula*) in the Hunter Catchment Endangered Population*" included in the biodiversity offset strategy for the Bulga Coal optimisation project (Bulga Coal Management Pty Ltd 2013). Based on information available at the time, measures such as these are commensurate with obligations and responsibilities demanded under threatened species legislation. The new evidence discussed in this paper raises the possibility that a change may be required in the management of *Acacia pendula* in the Hunter; perhaps even recognising the species as an introduced woody weed rather than a species of high conservation status. This is a difficult realisation to make, particularly for a region where *Acacia pendula* has been a flagship threatened species for at least a decade, and where government grants have been forthcoming for the management of remnant stands of this species and the community which it characterises (e.g. Thompson 2012). Prior to this, however, it is imperative that genetic studies be undertaken to identify the origins of current plants.

There are few precedents in the literature of listed significant plant species being delisted due to misidentification or confusion over origins. Schaefer et al. (2011) report on the single-population endemic *Marsilea azorica* from the Azores in the northern Atlantic, described in 1983 and listed as critically endangered on the IUCN red list and considered a species of conservation priority in Europe. Following

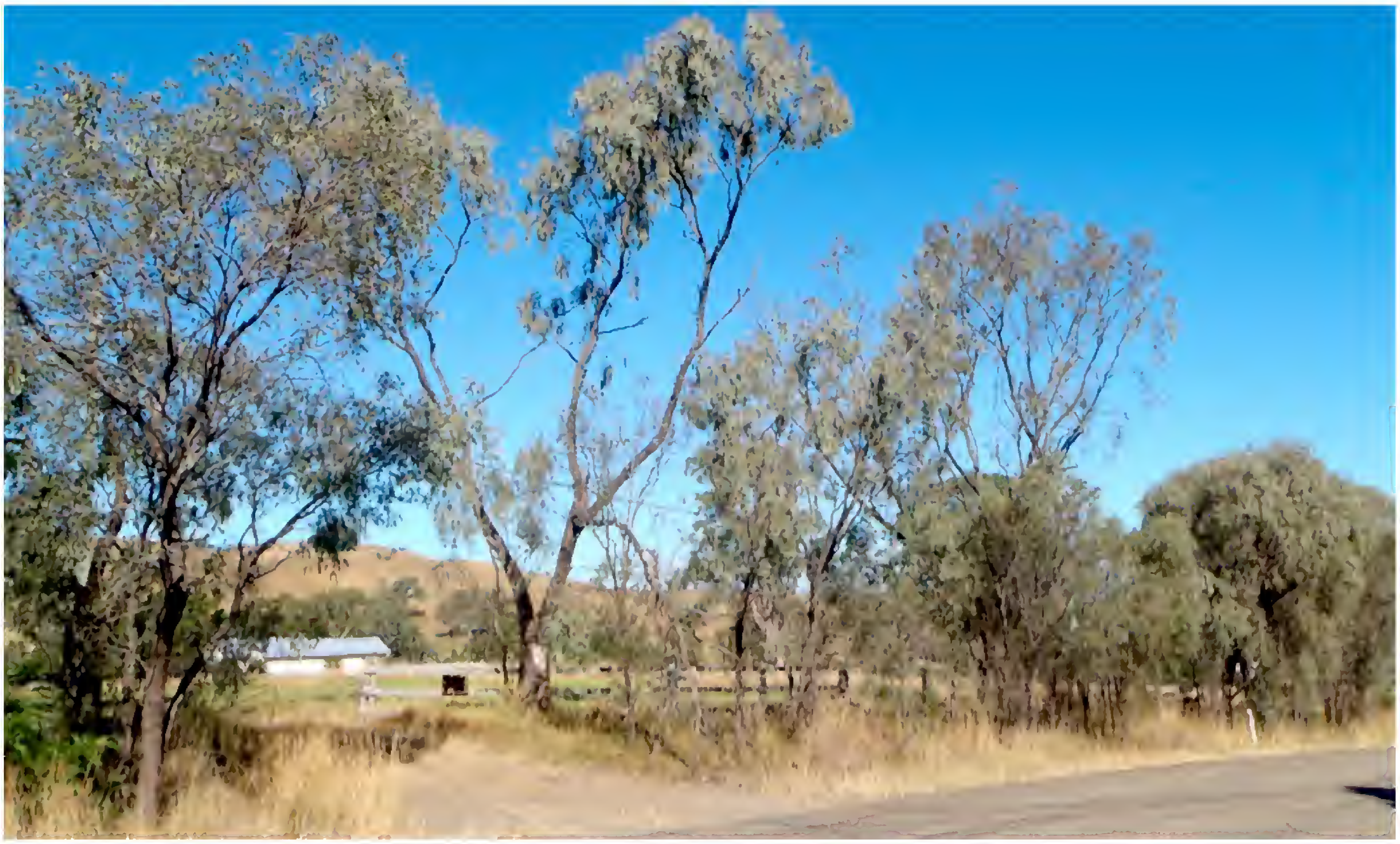

Fig. 5. *Acacia pendula* naturalising along the road at Bingleburra, between East Gresford and Dungog. Note the original, taller planted trees along the fenceline, and the younger plants recruited probably after seed scarification by roadworks.

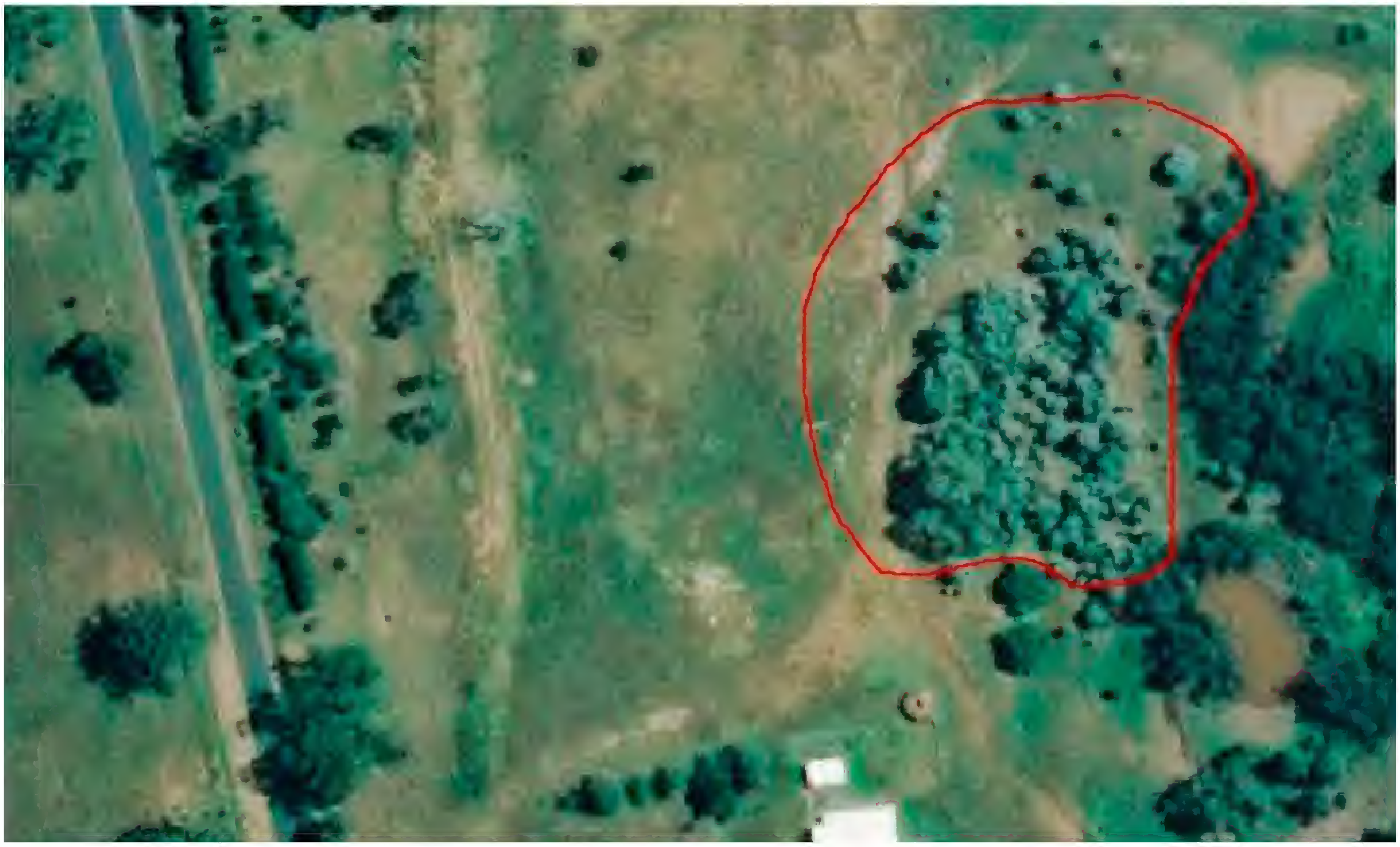

Fig. 6. Aerial view of *Acacia pendula* naturalising at a property near Muswellbrook. The original, taller planted trees occur on the left hand side of the stand. Scale 1:1000.

morphological and molecular data analysis, Schaefer et al. (2011) demonstrated that this taxon was alien to the region, conspecific with the Australian *Marsilea hirsuta*, and consequently recommended removal from all conservation priority lists. In this case, taxonomic confusion led to the application of the highest conservation priority ranking within Macaronesia for a species, despite the relatively late (1983) discovery of the taxon along a roadside within a heavily grazed landscape. In a remarkable parallel with *Acacia pendula*, *Marsilea* was not mentioned in any of the plant inventories prepared during the 1800s, and field-based plant lists failed to record the genus for the first 70 years of the 20th century (Schaefer et al. 2011).

A second example is an aquatic species occurring within the port of Newcastle at the mouth of the Hunter River. In studying the germination characteristics of the New South Wales listed endangered *Zannichellia palustris*, Greenwood and DuBowy (2005) postulated that this Western European and North American aquatic species may have been introduced to Australia through trans-national shipping, and should be regarded as an exotic, naturalised species rather than one of conservation significance. The few Australian records for a species with high fecundity and abundance in other parts of the world, and the finding by Greenwood and DuBowy (2005) that cool water temperatures and low salinity are required to induce germination, lend support to this hypothesis. At present, however, this species remains listed as endangered in New South Wales. Similarly, while not dealing with threatened species, Mills (2009, 2010) discusses problems in the definition of indigenous species from Norfolk Island, where land management agencies grapple with control of native and introduced taxa.

It may be argued that there is some merit in the protection of *Acacia pendula* in the Hunter Valley, given the extent to which the species characterises threatened ecological communities in interior parts of Australia; as noted previously, the species is listed as threatened as various entities across three States. But is it possible that protection of *Acacia pendula* in the Hunter through endangered species legislation may actually be posing a threat to the naturally occurring and endangered grassy woodlands that occupy much of the valley floor remnants? Many stands of *Acacia pendula* have formed dense thickets of plants as a result of root suckering following the easing of grazing pressure; indeed, new stands are now emerging from subterranean roots in grazing land where stock have been completely removed. It is likely that the 2050 'juvenile' *Acacia pendula* reported by Bulga Coal Management Pty Ltd (2013) for one site are merely root suckers following stock removal. At Wambo, sampling of all species present in 2007 showed there to be very few shrub and ground-layer species evident, and it was postulated that resource competition induced from dense shading or allelopathy may be the limiting factor (Bell 2007).

How conceivable is it that by protecting *Acacia pendula* we may be promoting an emerging threat to the endangered forests and woodlands of the Hunter (the State-listed *Central Hunter Grey Box – Ironbark Woodland, Central Hunter Ironbark – Spotted Gum – Grey Box Forest, Hunter Valley Footslopes Slaty Gum Woodland, Hunter Lowlands Redgum Forest*, and *White Box – Yellow Box – Blakely's Redgum Woodland*; and the Commonwealth *White Box – Yellow Box – Blakely's Redgum Grassy Woodland and Derived Native Grassland* and the nominated *Hunter Valley Remnant Open Forests and Woodlands*)? Cuneo and Leishman (2013) have recently outlined the threats posed by the invasive African Olive (*Olea europea* subsp. *cuspidata*) in the threatened grassy woodlands of the Cumberland Plain in western Sydney. They found that the capacity of this species to form dense stands of shrubs to 10 m in height, decreasing the diversity of native grassy woodland species, posed a significant threat to Cumberland Plain Woodland. Regenerating stands of *Acacia pendula*, particularly morpho-types B and C, appear to be projecting a similar threat onto the threatened grassy woodlands of the Hunter, performing the role of 'ecological engineer' in the terminology of Cuneo & Leishman (2013) as it alters the structural makeup of the vegetation. Similarly, Radford et al. (2001) noted that *Acacia nilotica*, originally introduced from Africa as a stock browse and shade species, has now spread to become a serious weed in parts of the Northern Territory. Reid and Murphy (2008) discuss the implications for herbaria when identification of native Acacias is confused with weedy introduced species which may go un-noticed. Further investigations into the population dynamics of *Acacia pendula* and invasive species research is required to address issues such as these.

There is an urgent need for genetic studies

There is clearly an urgent need for genetic studies to be undertaken on Hunter Valley plants to validate the concerns raised in this paper. As with investigations into other arid-zone Acacias (e.g. Miller et al. 2002; Page et al. 2011; O'Brien et al. 2014) this should aim to clarify origins and define taxonomic limits of *Acacia pendula* and its close relatives, and should encompass all three Hunter Valley morpho-types recognised here. Some preliminary work on this issue has commenced, and *Acacia pendula* is now included in the *Restore & Renew NSW* research project being co-ordinated by the Royal Botanic Gardens and Domain Trust in Sydney (http://www.rbgsyd.nsw.gov.au/science/Evolutionary_Ecology_Research/RestoreNSW). Should genetic studies show that parts of the Hunter Valley population of *Acacia pendula* (e.g. morpho-types B and/or C) are distinct new species, then appropriate conservation measures should be implemented.

Conclusion

For the long-term protection of threatened ecosystems in the Hunter Valley, there is a need to seriously review the genetic integrity, taxonomic position, conservation status and management of *Acacia pendula* stands that occur there. Evidence from early explorers, herbarium and database records, and habitat characteristics raise a number of doubts over the validity of currently accepted understandings, and advocate such a review. Until then (and to paraphrase the words of McDougall (2004) when he was debating the weedy or threatened status of *Ammobium alatum* in southeastern Australia), all new populations of *Acacia pendula* well outside of its historical range (which would include the Hunter Valley) should perhaps be regarded as weedy in whatever situation they occur, irrespective of their determined identities. Such a view is problematic, however, given the current listing of *Acacia pendula* as a threatened population and a characteristic species in two endangered ecological communities. In the interim, the 'shifting baseline' syndrome discussed by Clavero (2014) is apt to encapsulate the Hunter *Acacia pendula* population: that which adopts new species into the assumed normal or desirable state of natural systems, compelling societies to monitor, protect and restore them when they become threatened. The practical management implications of such a syndrome are important to understand fully: there may well be other taxa within the Hunter region, or indeed elsewhere in New South Wales, that are currently unnecessarily protected through legislation, channelling limited recovery funding away from more legitimate threatened taxa.

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Peak flowering and fruiting patterns in the endangered orchid *Corunastylis* sp. 'Charmhaven' on the Central Coast of New South Wales

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Abstract**:** Population size, and flowering and fruiting developmental stages in the Critically Endangered species *Corunastylis* sp. 'Charmhaven' (Family Orchidaceae, formerly included within genus *Genoplesium*), were investigated in the Warnervale-Charmhaven area over a three year period. Population size in 2012 was 11 plants, in 2013, 14 plants and in 2014 increased to 26 plants, with new plants appearing near the original plants. Proactive management, including mowing and erecting wire protective cages around groups of orchids was partly responsible for this increase in numbers because it prevented browsing by rabbits but only ten plants carried fruits to maturity in the 2014 season to produce seed. Despite an increase in numbers over a couple of years, a population of 26 individuals is very small and warrants maintaining the current conservation listing of Critically Endangered.

The population began to flower between 15th and 29th February in 2012 and from 3rd to 14th March in 2013. However in 2014 flowering began on 11th February and extended to 19th March but it took until 17th June to reach the seed dispersal stage. 2014 involved two phases of flowering; whether climatic factors were responsible for this event is not known.

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Introduction

Corunastylis sp. 'Charmhaven' is a terrestrial tuberous herb in the family Orchidaceae with an inflorescence approximately 20 cm long, with up to nine flowers in a well-spaced spike 1.4 cm long. The flowers have green sepals and petals suffused and striped with deep red brown and a burgundyicoloured, densely ciliate, obovate labellum with a mucronate tip (P.H. Weston, in NSW Scientific Committee 2012). This contrasts with the acuminate apex of the hairy labellum in the related *Corunastylis fimbriata* which is similar to *Corunastylis* sp. 'Charmhaven' and occurs with it at the Charmhaven site. Many more flowers are usually present on the spike of *Corunastylis fimbriata*. Dorsal sepals of *Corunastylis* sp. 'Charmhaven' are wide, ovate and hooded with the lateral sepals being narrow, ovate, bent abaxially, erect and ascending.

Corunastylis was formerly treated taxonomically as part of *Genoplesium* (the 'pygmy prasophyllums' – see Jones & Clements 1989), but was regarded as a distinct genus by Jones et al. (2002), who resurrected the name *Corunastylis* Fitzg. for it. The most recent taxonomic account of *Corunastylis* is provided by Jones (2006).

Corunastylis sp. 'Charmhaven' is confined to the Warnervale-Charmhaven area (latitude -33°14'16", longitude 151°29'28") in the Shire of Wyong on the Central Coast of New South Wales. The species was first found at Charmhaven in 2012 on private property. At Warnervale a few individuals, also on private property, along with a single individual on

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government land have been found in subsequent searches. Because of its small population size and very restricted distribution, *Corunastylis sp.* 'Charmhaven' is listed as critically endangered on Part 1 of schedule 1A of the NSW *Threatened Species Conservation Act, 1995.*

Charmhaven supports the largest population of *Corunastylis sp.* 'Charmhaven' and three years of searching and monitoring of the population there have now been completed. The project began in 2012 as an investigation to search and locate plants, followed in 2013 by protection of the species from browsing rabbits and mowing, and in 2014 monitoring of the flowering and fruiting stages and measuring various plant parts. In 2013 all energy was devoted to managing the orchid plants from browsing by rabbits with the construction and placement of wire protection cages. This communication is a summary of those results.

Methods

Populations of *Corunastylis sp.* 'Charmhaven' are found associated with Patonga Claystone geology of the Clifton subgroup and the Narrabeen group of rocks which produces saline soils. Vegetation at the Charmhaven site is remnant heathland (See Appendix 3 for a description of the vegetation and the plant species list for the vegetation associated with the orchid at the Charmhaven site). At the Warnervale site (on government land) there is Spotted Gum-Ironbark Forest (*Corymbia maculata – Eucalyptus fibrosa–Eucalyptus capitellata – Eucalyptus globoidea*) with a conspicuous *Melaleuca nodosa* understorey and at Warnervale (on private property) the few individuals are found beneath a group of scattered trees in a paddock.

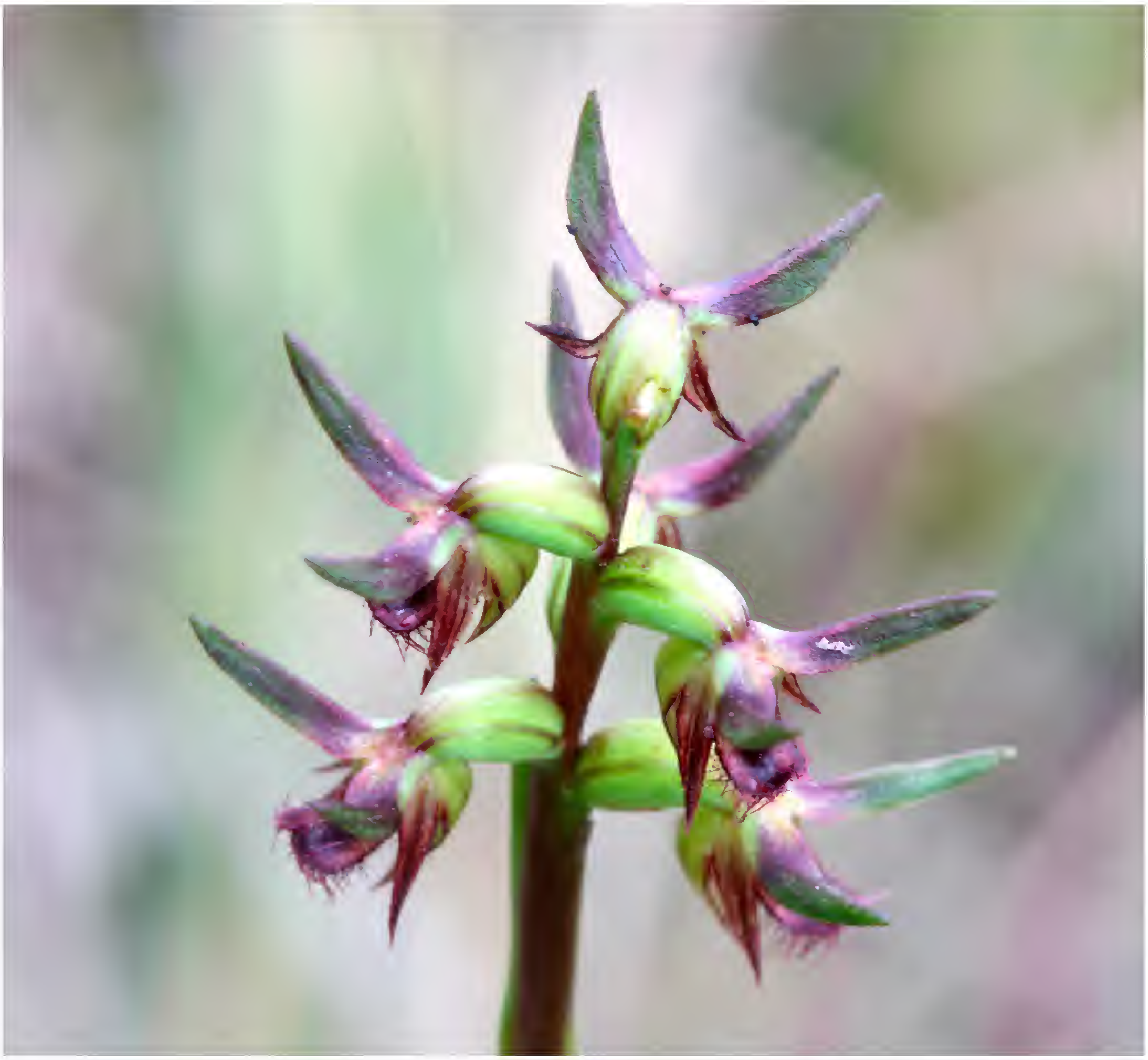

Fig. 1a. In flower showing distinctive rectangular labellum

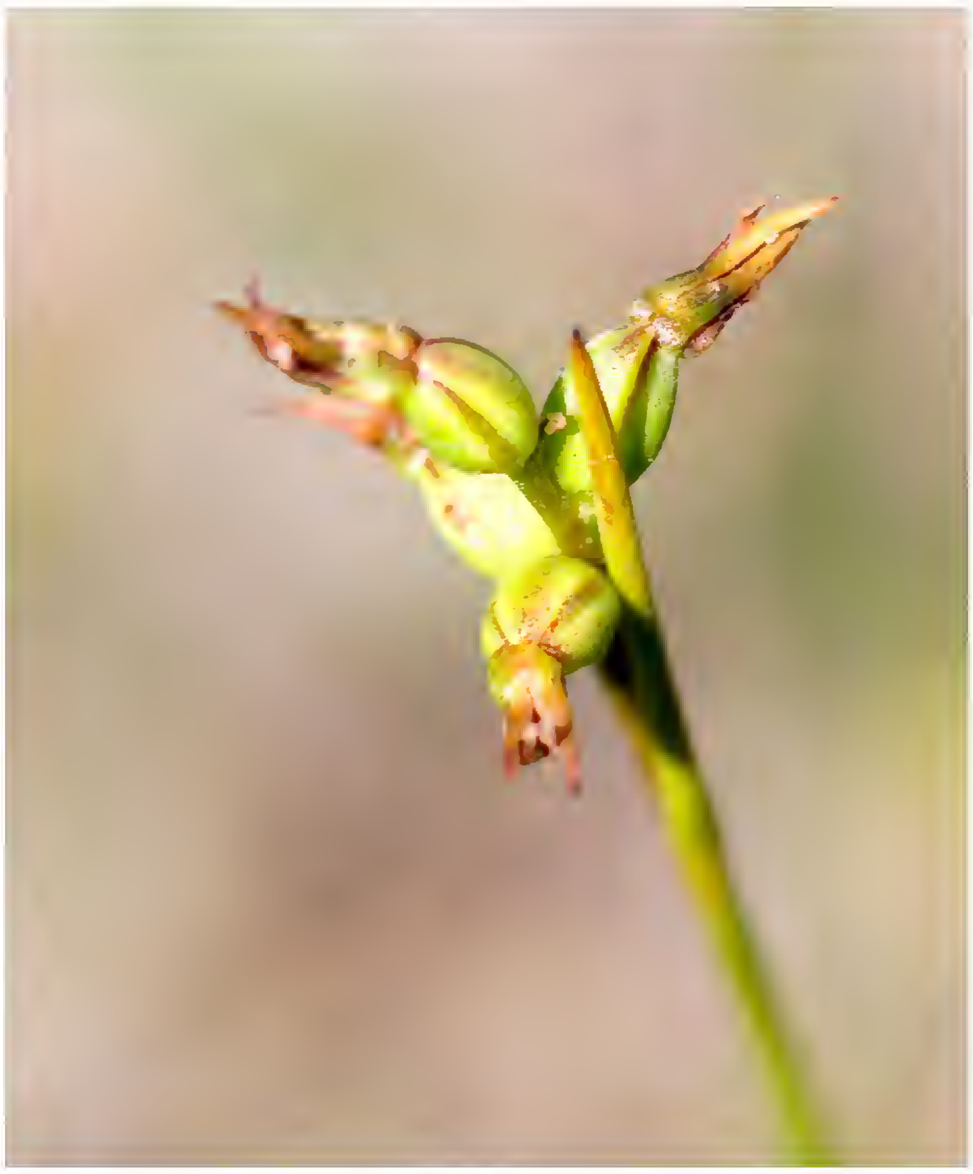

Fig. 1b. Early ovary enlargement stage with flowers waned

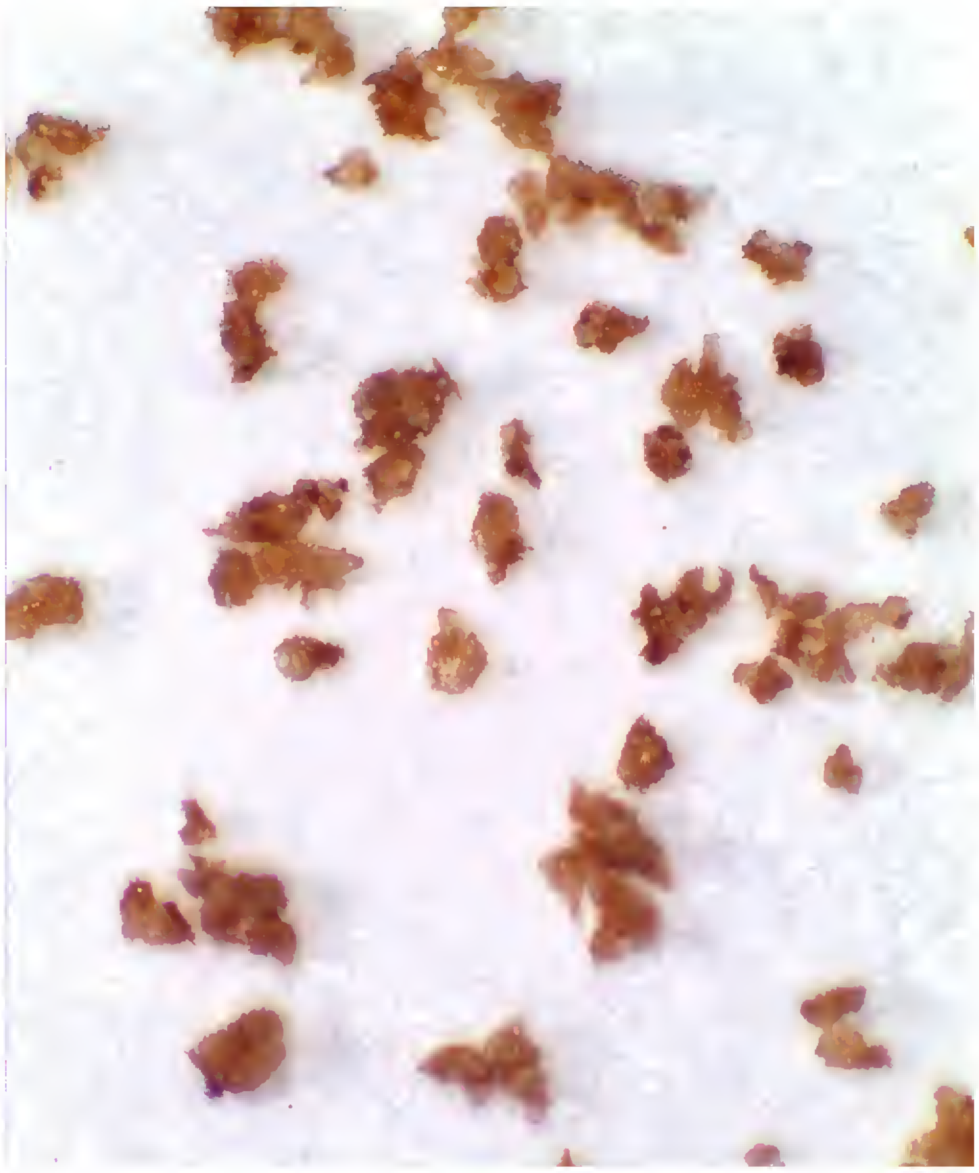

Fig. 1d. Most of the seed from the 2013 season does not appear to be fully formed. (Australian Botanic Garden photo).

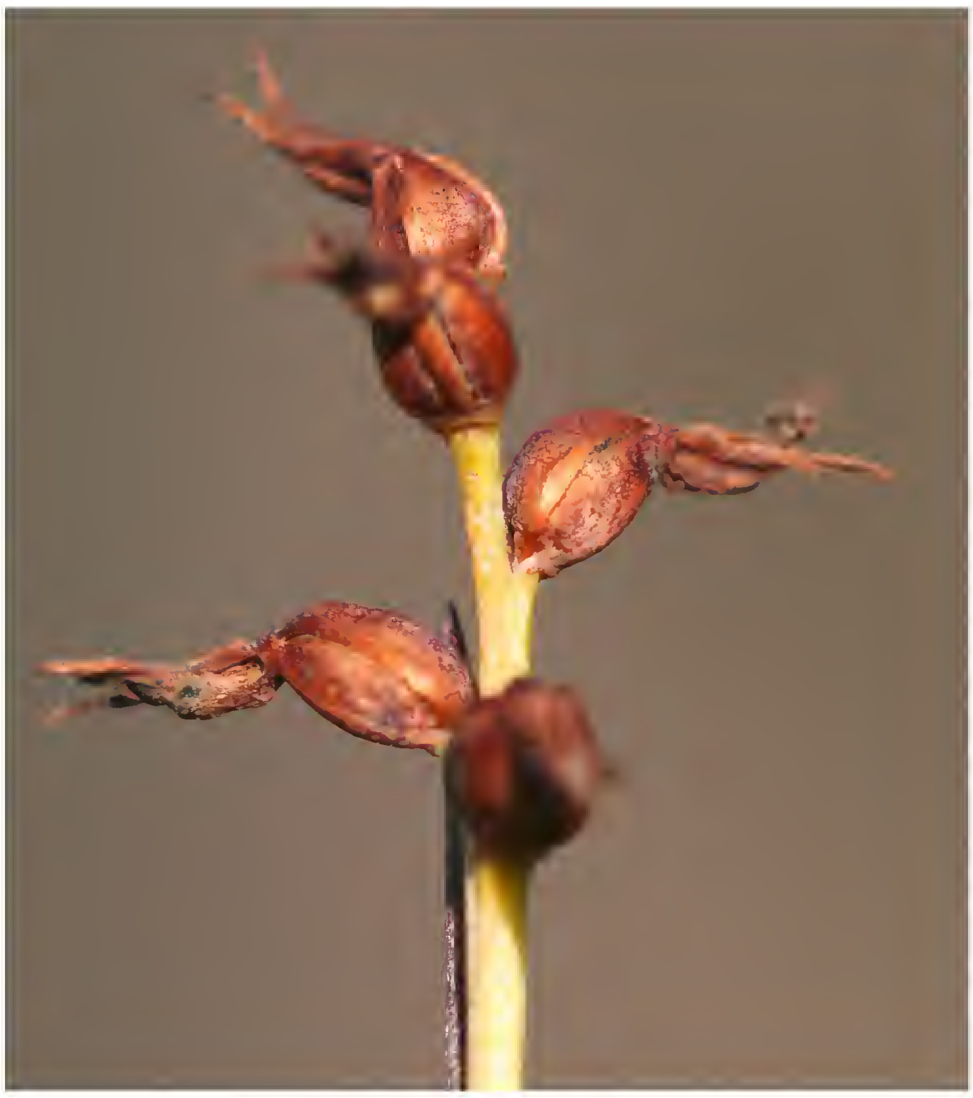

Fig. 1c. Late ovary development stage showing brown coloured capsules and withered sepals and petals. The capsule has not yet split to release seed.

Two other *Corunastylis* species also occur at the Charmhaven site. *Corunastylis fimbriata* occurs just upslope of it and flowers at the same time as *Corunastylis sp.* 'Charmhaven'. *Corunastylis insignis,* is also present amongst the *Corunastylis sp.* 'Charmhaven' population but flowers at the beginning of September. *Corunastylis insignis* is listed as endangered on the *TSC Act, 1995.*

The population of *Corunastylis sp.* 'Charmhaven' is on 1.6 hectares of private property at Charmhaven and has been monitored over three years (2012–2014). As a safeguard against damage and vandalism the property has been fenced to deny public access to the orchids. The area in which they grow is also within a Bushfire Asset Protection Zone (APZ) and is subject to maintenance mowing to reduce fuel. Details of the location of the plants are held by the NSW Office of Environment and Heritage (Office of the Premier and Cabinet) as wildlife atlas records.

Monitoring and recording over the three year period (2012–2014) involved regular site visits mainly between seven and ten days apart. The initial 2012 site visits focused on finding individual plants and recording their position using an Ashtech-Trimble Differential Global Positioning System (DGPS) which gave a precision of between 1–2 metres in position, but for orchids in a restricted space that degree of precision is not acceptable. The recording was improved in 2014 when the topographical/cadastral surveyor's plan was upgraded, allowing measurements of individual orchids to be undertaken from the cadastral corner peg along the existing fence line and then normal to the fenceline to each of the orchid plants found. The information was then transferred to the computerised survey plan, and MGA zone 56 co-ordinates derived for each orchid. This improved the precision to < 0.5m in position and is necessary where development is proposed near small groups of rare plants.

Time spent during the 2012 survey enabled five developmental phases of the growing *Corunastylis* plants to be defined and photographed (Figures 1a, 1d, 1c). In 2014 the surveys recorded the timing of each of the flowering and fruiting phases and included measurements of some morphological characters. The height of the stem (i.e. from the ground to the top of the stem), the rachis (ie from the top of the stem then along its length to the node of the basal flower), leaf length and the length and width of the capsules were measured. Counts of the number of flowers in the inflorescence were also recorded. These additional measurements were taken at the request of Dr Peter Weston of the National Herbarium of New South Wales and some of the details can now be used to refine the measurements in the description of the species that is currently being prepared (Peter Weston in lit.)

Results

Population size

In 2012 the population size at Charmhaven was 11 plants (Figure 2), with `14 plants in 2013. In 2014 the population increased to 26 plants, some of which appeared elsewhere near the original plants. Not all plants carried fruits to the capsule dehiscent stage to allow the release of seeds.

Stages of development

In 2012 five plants of *Corunastylis sp.* 'Charmhaven' were recorded by 15th February with flowers reaching anthesis by 29th February; this phase was nominated as the flowering stage (Figure 1a). At the end of February eleven plants were present at five locations. Flowers remained open until 12th March, then began to wane and the ovaries began to enlarge. All petals and sepals began to wither. Maintenance mowing cut off nine of the plants (the area in which they grow is an asset protection zone) but the two that remained were measured on 23rd March 2012. This phase, recognisable by the green colouration of the ovaries, was recorded as the early ovary enlargement stage (Figure 1b). By 6th April 2012 only one orchid shoot remained (the other orchids having been browsed by rabbits) and at this stage the ovary colour turned from green to a brown colour and began to split at the apical end; this phase is referred to the late ovary stage (Figure 1c). The last orchid shoot remained until 22nd April, but failed to reach the capsule seed dehiscence stage.

In 2013 the orchids emerged by 13th March, approximately 15 days later than emergence in 2012. The number of flowering plants observed had increased from 11 in 2012 to 14 in 2013 though not all plants that flowered in 2012 re-emerged in 2013. Some of the 2013 emerging plants were present in different locations to those found in 2012 indicating some newly recorded plants were present. At this time rabbits were seen browsing on the orchids and wire cages were placed to protect each orchid plant. This procedure took most of the 2013 orchid flowering and fruiting season.

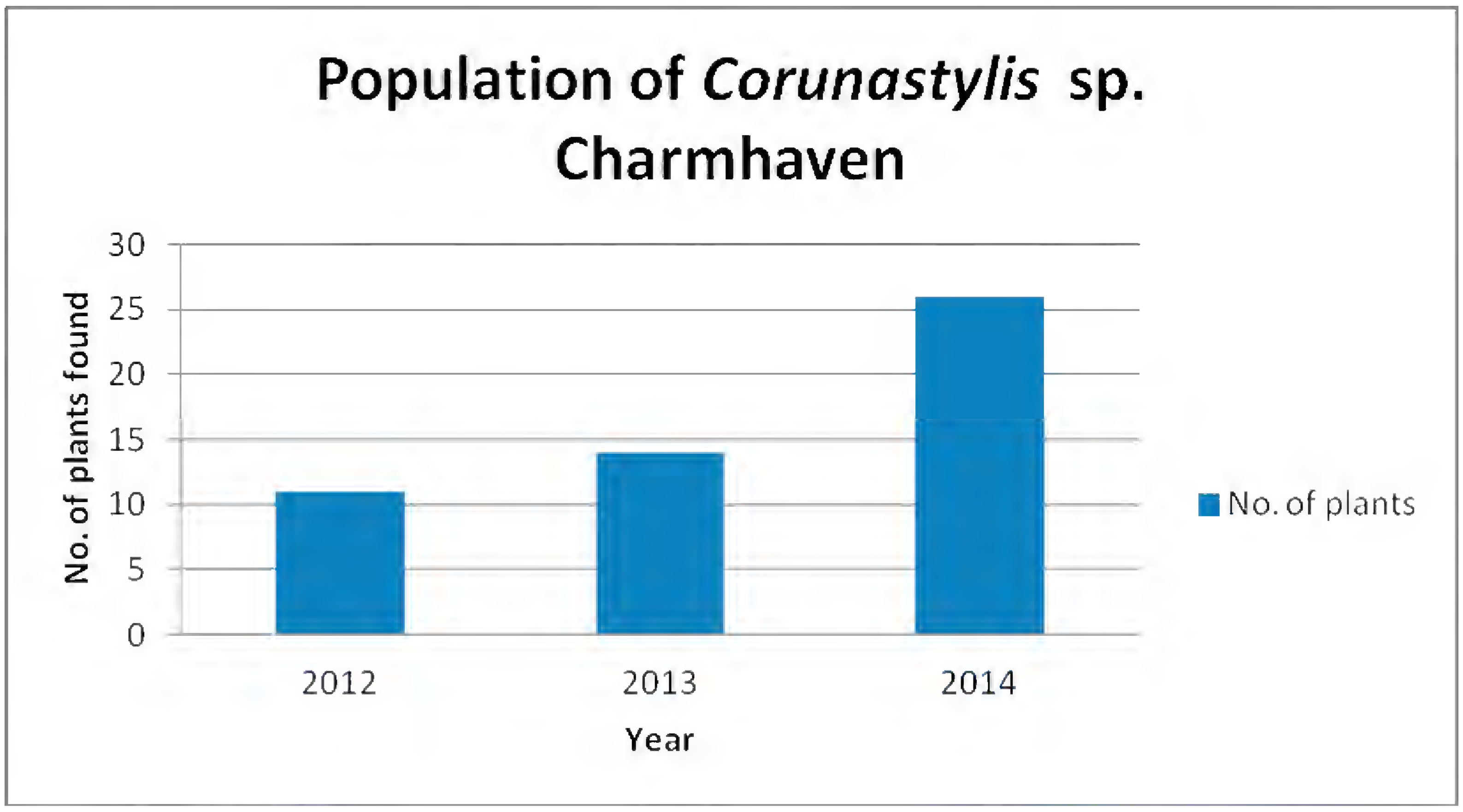

Fig. 2. Number of plants recorded in the *Corunastylis* sp. 'Charmhaven' population at the Charmhaven site 2012–2014. Not all plants survive to the capsule dehiscent stage to allow the release of seeds. Despite an increase in numbers in 2014 resulting from protecting plants from rabbits and introducing a specific mowing regime, a population of 26 individuals is very small and warrants the conservation listing of Critically Endangered.

Table 1: Morphological measurements for *Corunastylis sp.* 'Charmhaven' at Charmhaven in 2014.

Parameter	**Stem height(mm)**	**Leaf length (mm)**	**Rachis height (mm)**	**Flowers per inflorescence**	**Capsule**	
					Length (mm)	**Width (mm)**
Mean± standard error	189 ±8.9	15.5 ±1.3	12.5 ±1.1	4.1 ±0.2	4	2
No. of plants (n)	20	9	16	14	11	11

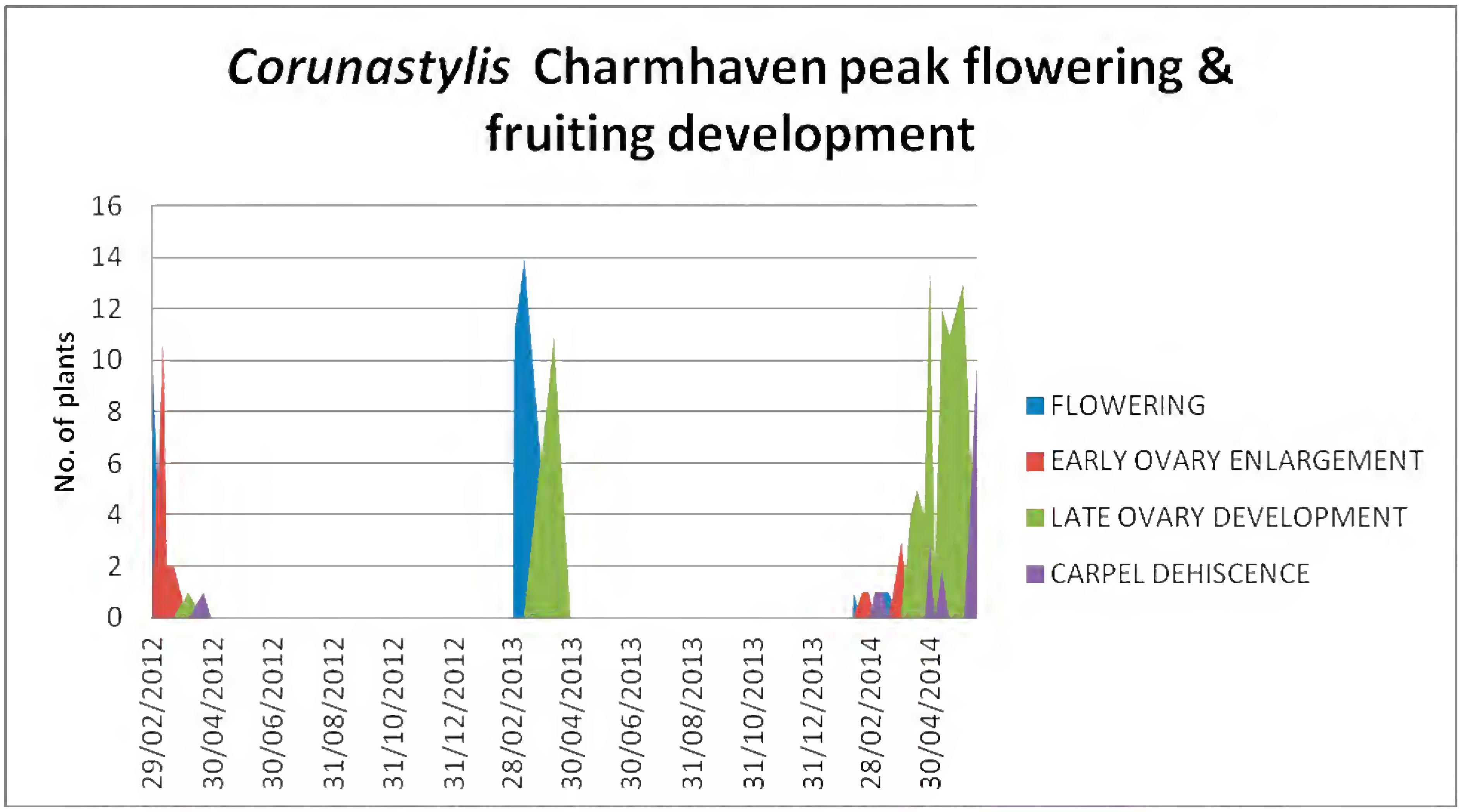

Fig. 3. Timing of flowering and fruiting development stages for *Corunastylis* sp 'Charmhaven' (2012–2014).

The 2014 survey was the most accurate survey conducted so far, as purposeful weekly visits and measurements were carried out rather than *ad hoc* visits. The orchid emergence in 2014 occurred at two distinct times (Figure 3). The initial emergence, however, only involved one orchid plant, which began to emerge early on 29th January 2014 (i.e. earlier than in 2012 or 2013), but did not flower until 11th February and by 20th February reached the ovary enlargement stage; it remained in that state until 27th February. From 5th March to 12 May it was in the late ovary enlargement stage and on 20th May was in the capsule dehiscent stage.

A second phase of emergence occurred approximately one month later. These plants were noted to be in bud on 12–19th March (three plants) with another two plants in flower at the same time. Not all of these plants reached the ovary enlargement stage. Three plants withered and their shoots died on 19th March whilst three plants reached the early ovary enlargement stage. Nineteen plants, however, did reach the late ovary enlargement stage by 30th April; some of these plants were not found until this stage had been reached because searching for the orchids amongst regenerating and mown heathland is a difficult task as the colour and form of this orchid blends in well with regenerating native vegetation. The late ovary enlargement stage was mostly from 10th April–20th May, although some plants terminated this stage before that date (combination of aborting fruits and the plant withering away). Those that reached the capsule dehiscent stage (n=10/26) did so by the 17th June when the capsules were just beginning to split (Figure 3). Microscopic examination of the split capsules revealed the presence of seeds (Figure 1d).

Overall, the flowering and fruiting pattern is complicated because of the variation in timing of the stages and because not all of the shoots survive to capsule dehiscence. The data revealed a relatively consistent flowering pattern, which can change in time probably according to climatic conditions. Details are given in Appendices 1 & 2. At the end of the investigation the positions of the orchid plants were marked with a cat's eye reflector 300mm west of each plant, held in place on the ground with a 200mm long bolt.

Morphological measurements

Leaf measurements of *Corunastylis sp.* 'Charmhaven' were only undertaken in the early growing stages because ithe leaf withers away early; this is the reason for the low number of measurements (Table 1). Capsule length and width measurements were taken from only eleven plants due to

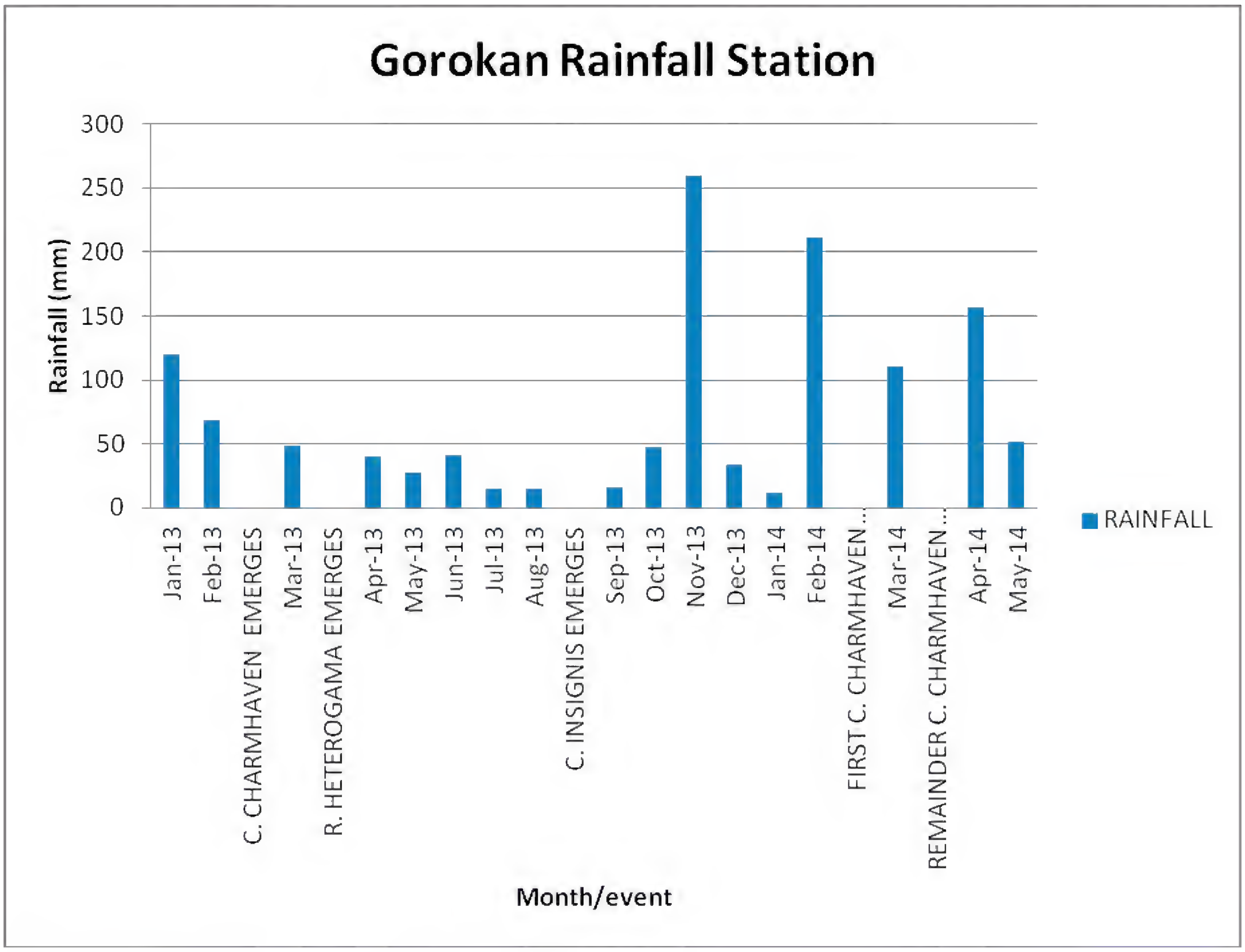

Fig. 4. Monthly rainfall for Gorokan for 2013–2014 showing associated *Corunastylis* sp 'Charmhaven' and *Corunastylis insignis* emergence. The co-occurring rare daisy *Rutidosus heterogama* has been included.

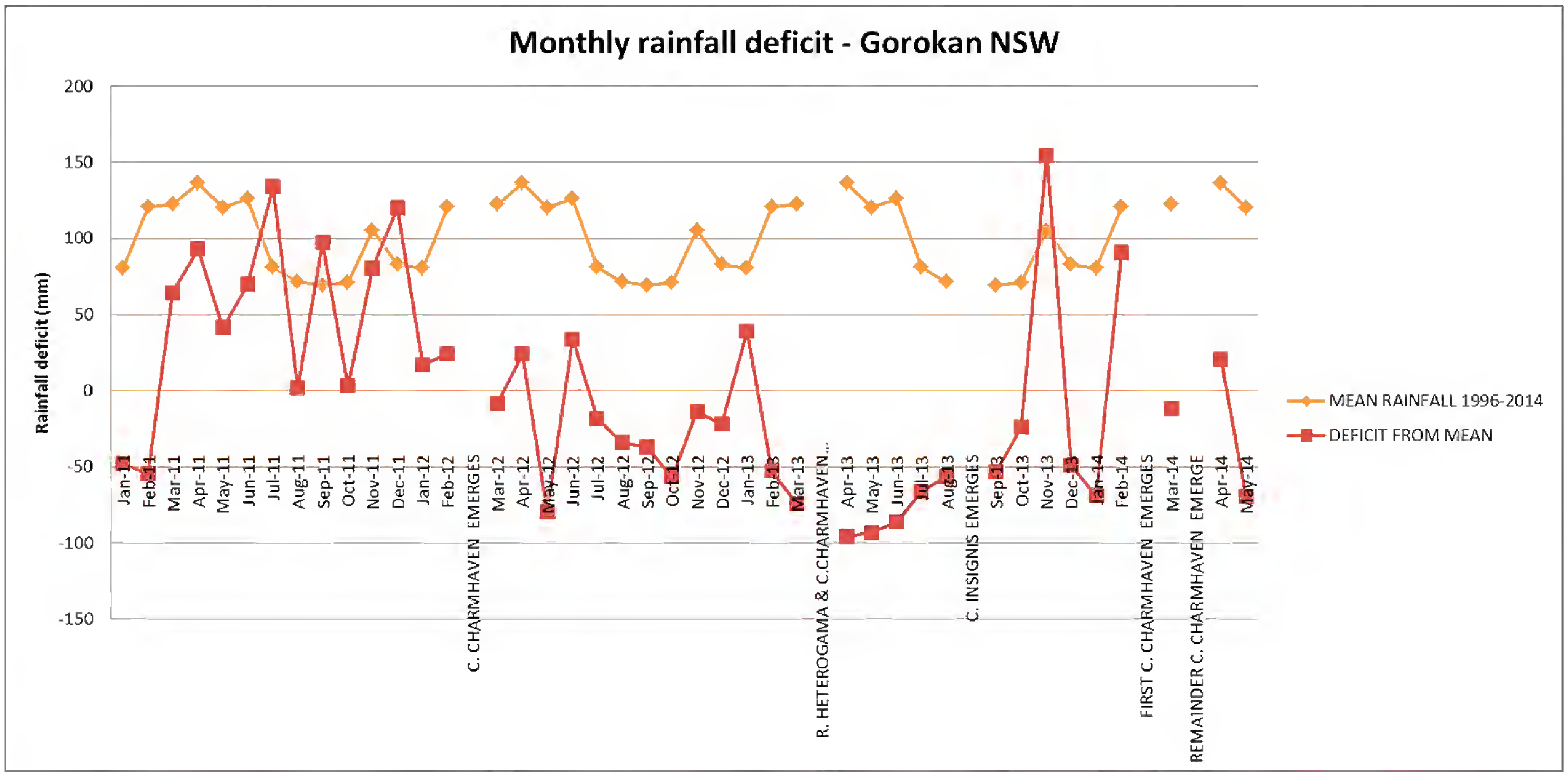

Fig. 5. Graph showing the 2012–2014 emergence of rare plant species *Corunastylis* sp 'Charmhaven' and *Corunastylis insignis* and the co-occurring rare daisy *Rutidosus heterogama* in relation to rainfall deficits and peaks from the mean annual rainfall. Source Gorokan rainfall station

the individual plants withering away and losing their fertile parts. Measurements were undertaken with a drawing scale with 1mm intervals; higher quality measurement would be achieved with a micrometer. The mean number of flowers per inflorescence was 4.1 based on a count of 14 plants in 2014, though in 2012, when the orchid was first found, photographs show up to nine flowers can be present in the inflorescence. In comparison in the similar species *Corunastylis fimbriata* there can be up to 30 flowers overall (Jones, 2006).

Discussion

Corunastylis plants are seasonally deciduous perennial herbs with paired tubers, one of which is replaced annually (Jones, 2006). The population size recorded at Charmhaven increased from 11 plants in 2012 to 26 plants, some of which appeared elsewhere near the original plants in 2014. Not all shoots survived to the capsule dehiscent stage to allow the release of seeds. The population may be expanding in the mowed open area and proactive management, by erecting wire protective cages around each orchid or group of orchids was partly responsible for this increase in numbers because it prevented browsing by rabbits. Alternatively, the number of plants present may be static but the numbers emerging and flowering may have increased between 2012 and 2014. Some of the plants caged in 2013 re-emerged in 2014 but a greater number of emergent new plants were found elsewhere over the site, and may have originated from newly germinating seeds. Despite an increase in numbers over a couple of years, a population of 26 individuals is very small and warrants the conservation listing of Critically Endangered.

Peak flowering of *Corunastylis sp.* 'Charmhaven' for the years 2012 and 2013 began in late February and took about two months to the end of the fruiting stage. However, in 2014 there appeared to be two phases of flowering and fruiting, the first of which was similar to the 2013 and 2014 seasons but the second phase began later, in mid to late March and extended to mid June (when the capsules began to dehisce). Seed-bearing capsules were produced during this second stage.

The cause of this alteration in timing in 2014 is not known with confidence but may be partly related to rainfall. Preliminary

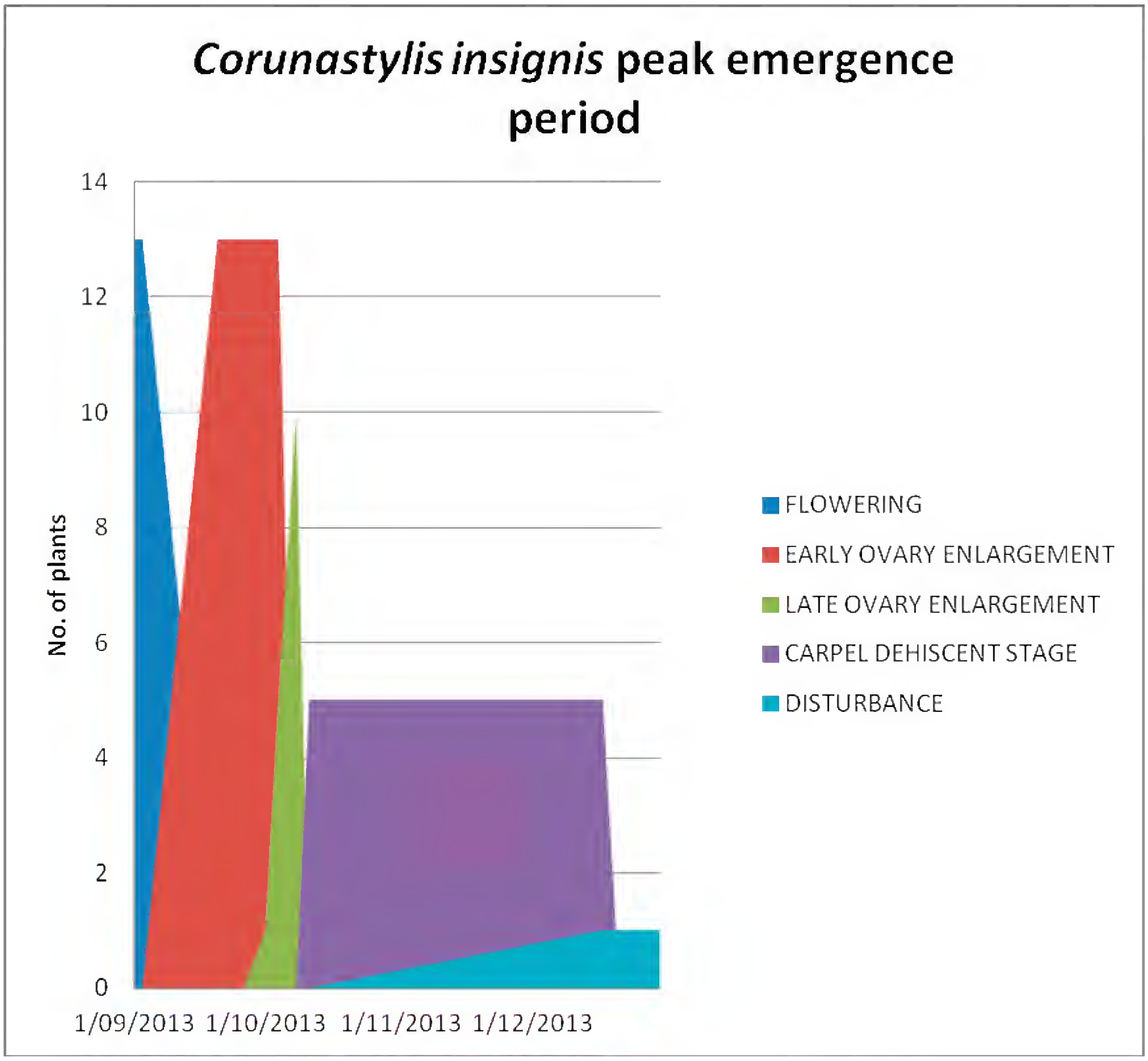

Fig. 6. Timing and stages of flowering and fruiting of *Corunastylis insignis* in 2013 (disturbance was caused by trail bikes).

investigation of rainfall does reveal a lengthy deficit (Figures 4, 5) between January and October 2013. A short wet period is evident in February 2014 just prior to flowering but that alone does not explain the two phases of flowering. There is also a deficit in March 2014 (Figure 5) although it is generally known that autumn temperatures were generally higher than normal this year. The local climate station at Norah Head did not record adequate temperature data to investigate this matter further. Nevertheless, it was noted that prior to the second flowering phase the soil became very dry which led to it becoming very hard set, indicating a significant lack of soil moisture.

Another closely related species, *Corunastylis ectopa*, also a seasonal perennial, grows from an underground dormant tuber after summer rains and for the seeds to germinate there must be interaction with a mycorrhizal fungus (Frawley, 2010). It is likely that *Corunastylis sp.* 'Charmhaven' has similar requirements. *Corunostylis insignis*, which also occurs at the Charmhaven site, began flowering in 2013 on the 1st September and finished dehiscing seed on the 30th December (Figure 6). Flowering and fruiting stages occurred at the end of a very long dry period and summer rains did not appear until these phases had almost passed (Figures 4, 5). Seed set was successful.

Whatever the reason for the second, later flowering stage in *Corunastylis sp.* 'Charmhaven', peak flowering and fruiting extended into winter. The capsule dehiscent stage was sometimes reached, capsules did split and seeds were released, although photographs subsequently taken by The Australian Botanic Garden, Mount Annan indicate that most of the seeds from the 2013 season do not appear to be fully formed (Figure 1d). This may have implications for the long term maintenance of the population.

Rabbit control and mowing are the main management factors for the site. Mowing has been undertaken on a regular basis to protect the premises from fire. Under the original conditions of consent a mowing regime was required to create an Asset Protection Zone (APZ) of ground vegetation 5 cm high. The rare orchids have only appeared in the APZ which supported previously mature heathland, now mown down to ground level. Since the orchids have been found the mowing regime has been altered and the stem-leaf emergence and orchid flowering periods taken into account so they do not become damaged. By creating extra light conditions APZ management may be related to the observed increase in numbers of emergent rare orchids, though rainfall conditions may also be involved. Despite many botanical searches in the adjoining mature heathland vegetation none of the two rare orchids has been found in that habitat over the survey period.

Acknowledgements

The Australian Botanic Garden Seed Bank at Mount Annan (Richard Johnson) kindly organised the photographs of the seed of *Corunastylis sp.* 'Charmhaven 'and *Corunastylis insignis,* and Greg Bowman, manager of the private property, gave his time to help locate, cage and place permanent markers against the orchids at Charmhaven. An anonymous reviewer also made helpful suggestions and that help is acknowledged also.

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Manuscript accepted 2 December 2014

Appendix 1. Flowering phenology of *Corunastylis* sp. *'Charmhaven'* at Charmhaven site 2012–2013

DATE	Days between recording	Cumulative no of days	PHENOLOGY	REMARKS
15/02/2012	1	1	Orchid emerged; Flowers present but not open.	Five plants present 18/02/2012. Photographed.
29/02/2012	14	14	Flowers fully open.	11 plants present at five locations 06/03/2012. Photographed.
12/03/2012	12	26	Flowers waning.	Ovary beginning to enlarge. All petals/sepals withering.
16/03/2012	4	30	Flowers waned. Ovary enlargement evident. Coloration green.	2 plants left due to mowing for the APZ. Photographed.
23/03/2012	7	37		Stems 15.6–21.9cm high x 0.75mm; ovary range 3–4mm long x 2–2.4mm wide; bract 21mm x 1mm. Maximum flowers number 7
06/04/2012	14	51	Enlarged ovary changes to brown coloration and beginning to split at apical end.	One orchid left. Photographed. The other orchids eaten by rabbits.
22/04/2012	16	67	Capsule dehiscence and seed production/ ejection not observed.	Last orchid mown.
03/03/2013	1	1	Orchids noted to have emerged with 11 new plants from 2012	
14/03/2013	11	11	14 plants in total counted.	Rabbits browsing.
13/04/2013	30	41	Orchids still emerged as cages re-pegged.	This was to prevent rabbit browsing.
29/01/2014	1	1	One orchid emerges. Status in bud.	By this time a number of cages damaged but five retrieved.
05/02/2014	7	7	Orchid still in bud	
11/02/2014	6	13	Orchid now in flower	
20/02/2014	9	21	Orchid now at ovary enlargement stage	

Appendix 2. Flowering phenology of *Corunastylis* 'Charmhaven' 2014

Plant No.	No. of Flowers (capsules)	Height of plant (mm)	Length of leaf (mm)	Rhachis length (mm)	In bud	In flower	Early ovary enlargement	Late ovary enlargement	Capsule dehiscence
4					12th Mar		Gone 19th Mar;	–	
3		112			12th Mar		Bud withering 19th Mar; gone 1st Apr;	–	
2	6	165	12			12th–19th Mar		Gone presumed died 1st Apr;	
1	1st June 4 x 2mm	247 10th Apr;						10th Apr; 17th Apr; 24th Apr; 30th Apr; 12th May; 20th May; 3rd June ;	17th June;
6a	4 1st June 4 x 2mm;	130			29th Jan –11th Feb		20th Feb–27th Feb	5th Mar; 10th Apr; 17th Apr; 24th Apr; 30th Apr; 12th May; 3rd June;	20th May; 17th June;
6b						12th Mar	Withered & dying 19th Mar; Dormant 24th Apr;		1x capsule 5th March; 3 x capsules 12th Mar; gone 20th May; dead 17thJune;

6c	3 (4) 1st June 4 x 2mm;	92, 19th Mar; 142, 1st Apr;	15, 19th Mar; 10, 1st Apr;	12, 1st Apr;	19th Mar		4x2, 1st Apr;	10th Apr; 17th Apr; 24th Apr; 30th Apr; 3rd June; dead 17th June;	
6d		176	16, 1st Apr;	20, 1st Apr;	–	–	4x2, 1st Apr;	10th Apr; 17th Apr; 30th Apr; gone 3rd June	
6e	6	340	17 3rd June	15, 3rd June				3rd June; gone 17th June	
6f	6	218 3rd June	Withered away 3rd June	15, 3rd June				3rd June; gone 17th June	
5(a)	–	199	18, 1st Apr;	20, 1st Apr;	–	–	4x2, 1st Apr;	10th Apr; 17th Apr; Gone 24th Apr;	20th May, 3rd June
5(b)								30th Apr; 12th May	Gone 20th May
5©									30th Apr;
5(d)									30th Apr;
7	4; 4x2mm 3rd June;	207, 17th Apr;		6, 17th Apr;	–	–	–	17th Apr; 24th Apr; 30th Apr; 12th May; 20th May;3rd June;	17th June
8(a)	3; 4x2mm 3rd June;	142 12th May		12, 12th May				30th Apr; 12th May; 20th May, 3rd June; 17th June	
8(b)	4	205 12th May		14 12th May				30th Apr; 12th May	20th May; 3rd June dormant
9(a)	3; 4x2mm 3rd June;	170 12th May		10 12th May				30th Apr; 12th May 20th May 3rd June;	17th June
9(b)	5; 4x2mm 3rd June;	204 12th May		18 12th May				30th Apr; 12th May; 20th May; 3rd June;	17th June
9(c)	4; 4x2mm 3rd June	196 12th May		12 12th May				30th Apr; 12th May; 20th May; 3rd June;	17th June
9(d)	5; 4x2mm 3rd June;	214 12th May		11 12th May				30th Apr; 12th May; 20th May; 3rd June;	17th June
10(a)	3; 4x2mm 3rd June;	192 12th May	13 12TH May	9 12th May				30th Apr; 12th May; 20th May; 3rd June;	17th June
10(b)	4; 4x2mm 3rd June;	202 12th May	18 12th May	11 12th May				12th May; 20th May;3rd June	17th June
11(a)	3	188 12th May	14 12th May	5 12th May				30th Apr	12th May; gone 20th May
11(b)								30th Apr;	Missing 12th May; cage disturbed+rabbit droppings
12	5	247 12th May	17 12th May	11 12th May				12th May 20th May	17th June

Appendix 3. Description of the vegetation and plant species list associated with the *Corunastylis* sp. *'Charmhaven'* site at Charmhaven

LOW WOODLAND Allocasuarina littoralis, Kunzea ambigua and Melaleuca nodosa WITH OPEN TO MOIST CLOSED HEATHLAND Kunzea ambigua, Melaleuca nodosa, Callistemon linearis and Schoenus brevifolius

Structure: Low woodland with a shrubby, undershrub, herb and grass understorey. In places moist conditions apply.

Habitat: Elevated sites confined to drier soils of the Narrabeen undifferentiated geological formation (Patonga Claystones). Gorokan soil landscape unit.

Distribution: Heath was well distributed in the Gorokan area but now is mostly cleared or very disturbed.

Floristic composition: *Allocasuarina littoralis* (Black She-oak) and *Kunzea ambigua* make up the main canopy layer. Lower shrubs include *Kunzea ambigua* (Tick Bush), *Melaleuca nodosa, Lambertia formosa* (Mountain Devil), *Hakea dactyloides, Isopogon anemonifolius* and *Callistemon linearis*. Low understorey species include *Lepyrodia scariosa, Entolasia stricta* (Wiry Panic), *Themeda australis* (Kangaroo Grass), *Epacris microphylla, Schoenus brevifolius* and *Ptilothrix duesta*.

Comments: The woodland/heath supports three threatened species; *Rutidosus heterogama*, *Corunastylis sp.* 'Charmhaven' and *Corunastylis insignis* (within the associated mown asset protection zone). The subject land supports mature heath in good condition and a patch that is mowed to maintain a firebreak called an asset protection zone (APZ). It is within the APZ that is constantly mowed that all three species occur. These three species could not be found in the mature heath.

Related Mapping units: MU31 Narrabeen Doyalson Coastal Woodland in latest Wyong LGA mapping.

Family	**Species**
Fabaceae (Mimosoideae)	*Acacia longifolia*
Apiaceae	*Actinotus minor*
Casuarinaceae	*Allocasuarina littoralis*
Loranthaceae	*Amyema congener*
Poaceae	*Anisopogon avenaceus*
Poaceae	*Austrodanthonia tenuior*
* Poaceae	*Axonopus fissifolius*
Proteaceae	*Banksia oblongifolia*
Fabaceae (Faboideae)	*Bossiaea obcordata*
Acanthaceae	*Brunoniella pumilio*
Colchicaceae	*Burchardia umbellata*
Orchidaceae	*Caladenia catenata*
Myrtaceae	*Callistemon linearis*
Lauraceae	*Cassytha glabella*
Lauraceae	*Cassytha pubescens*
Cyperaceae	*Chorizandra cymbaria*
Polygalaceae	*Comesperma defoliatum*
Polygalaceae	*Comesperma ericinum*
Orchidaceae	*Corunastylis fimbriata*
Orchidaceae	*Corunastylis insignis*
Orchidaceae	*Corunastylis* sp.Charmhaven
Cyperaceae	*Cyperus eragrostis*
Orchidaceae	*Diuris alba*
Orchidaceae	*Diuris aurea*
Sapindaceae	*Dodonaea triquetra*
Droseraceae	*Drosera lunata*
Droseraceae	*Drosera pygmaea*
Poaceae	*Entolasia stricta*
Epacridaceae	*Epacris microphylla*
Epacridaceae	*Epacris pulchella*
Cyperaceae	*Gahnia radula*
Cyperaceae	*Gahnia* spp.
Orchidaceae	*Glossodia minor*
Fabaceae (Faboideae)	*Gompholobium minus*
Haloragaceae	*Gonocarpus tetragynus*
Goodeniaceae	*Goodenia paniculata*
Proteaceae	*Grevillea humilis* subsp. *humilis*
Proteaceae	*Grevillea sericea*
Proteaceae	*Hakea dactyloides*
Dilleniaceae	*Hibbertia vestita*
*Clusiaceae	*Hypericum gramineum*
*Asteraceae	*Hypochaeris radicata*
Proteaceae	*Isopogon anemonifolius*
Myrtaceae	*Kunzea ambigua*
Proteaceae	*Lambertia formosa*
Cyperaceae	*Lepidosperma laterale*
Myrtaceae	*Leptospermum polygalifolium*
Myrtaceae	*Leptospermum trinervium*
Restionaceae	*Lepyrodia scariosa*
Lindsaeaceae	*Lindsaea linearis*
Lomandraceae	*Lomandra glauca*
Myrtaceae	*Melaleuca nodosa*
Myrtaceae	*Melaleuca quinquenervia*
Myrtaceae	*Melaleuca thymifolia*
Epacridaceae	*Melichrus procumbens*
Orchidaceae	*Microtis parviflora*
Fabaceae (Faboideae)	*Mirbelia rubiifolia*
*Asteraceae	*Onopodium acanthium* subsp. *acanthium*
Orchidaceae	*Orthoceras strictum*
Apocynaceae	*Parsonsia straminea*
Iridaceae	*Patersonia sericea*
Proteaceae	*Persoonia lanceolata*
Proteaceae	*Persoonia levis*
Proteaceae	*Petrophile pulchella*
*Phytolaccaceae	*Phytolacca octandra*
Orchidaceae	*Prasophyllum elatum*
Cyperaceae	*Ptilothrix deusta*
Fabaceae (Faboideae)	*Pultenaea paleacea*
Fabaceae (Faboideae)	*Pultenaea rosmarinifolia*
Fabaceae (Faboideae)	*Pultenaea tuberculata*
Asteraceae	*Rutidosis heterogama*
Goodeniaceae	*Scaevola ramosissima*
Cyperaceae	*Schoenus brevifolius*
Lamiaceae	*Scutellaria* spp.
Goodeniaceae	*Selliera radicans*
*Poaceae	*Setaria italica*
*Solanaceae	*Solanum nigrum*
Orchidaceae	*Spiranthes australis*
Stackhousiaceae	*Stackhousia nuda*
Stylidiaceae	*Stylidium graminifolium*
Orchidaceae	*Thelymitra carnea*
Poaceae	*Themeda australis*
Anthericaceae	*Thysanotus juncifolius*
Anthericaceae	*Thysanotus tuberosus*
Apiaceae	*Trachymene incisa*
Anthericaceae	*Tricoryne simplex*
Goodeniaceae	*Velleia spathulata*
Xanthorrhoeaceae	*Xanthorrhoea resinifera*
Xyridaceae	*Xyris operculata*

Species highlighted * are exotic.